Summary of the BCHydro GMPE for Subduction Earthquakes

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Status of BCHydro Model

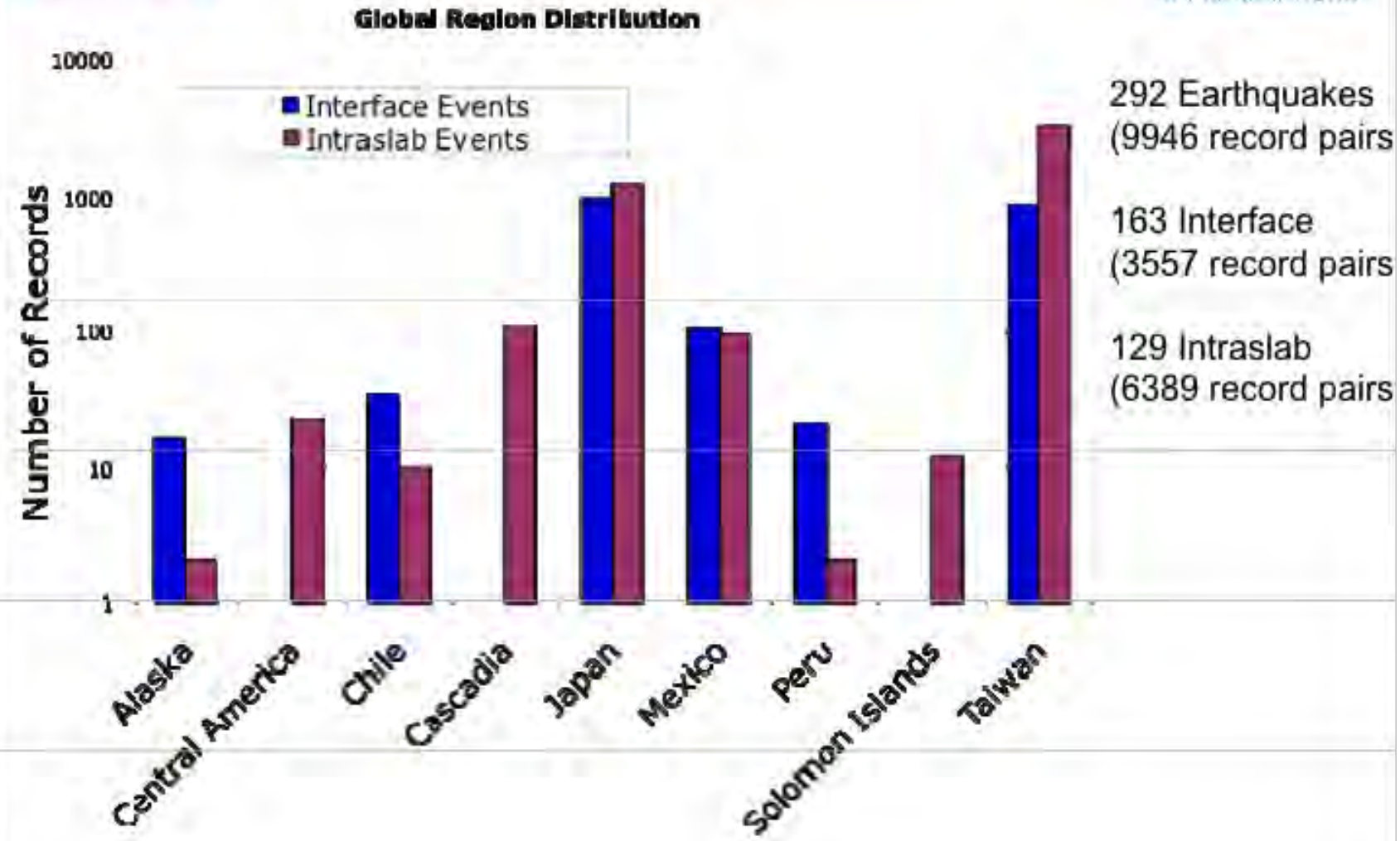
- Submitted to Earthquake Spectra (May 2012)
- Review Comments received
  - Requires changes to text, but not to model
  - Will resubmit in Jan 2013

Data Set

- Combined available data through 2007
  - Youngs et al (1997) - global
  - Atkinson & Boore (2003) - global
  - Zhao et al (2006) - Japan
  - Lin and Lee (2008) – Taiwan
  - Macias & Atkinson (2009) – Central America
  - Other available data
  - About 6000 recordings from 292 earthquakes in full set
- 2010 Chile and 2011 Tohoku
  - Not included in data set, but model adjusted based on these data

Datasets

BC hydro
FOR GENERATIONS



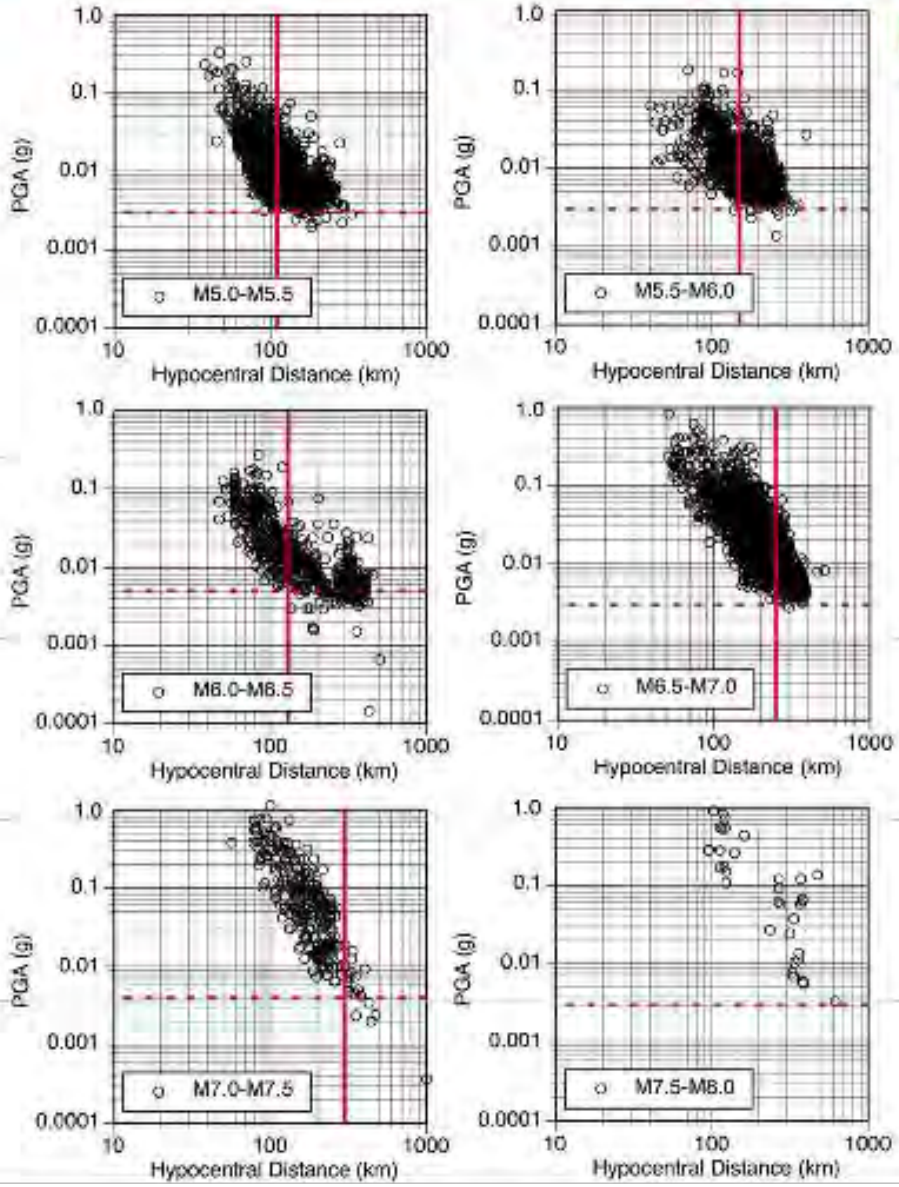
292 Earthquakes
(9946 record pairs

163 Interface
(3557 record pairs

129 Intraslab
(6389 record pairs

Slab Dataset

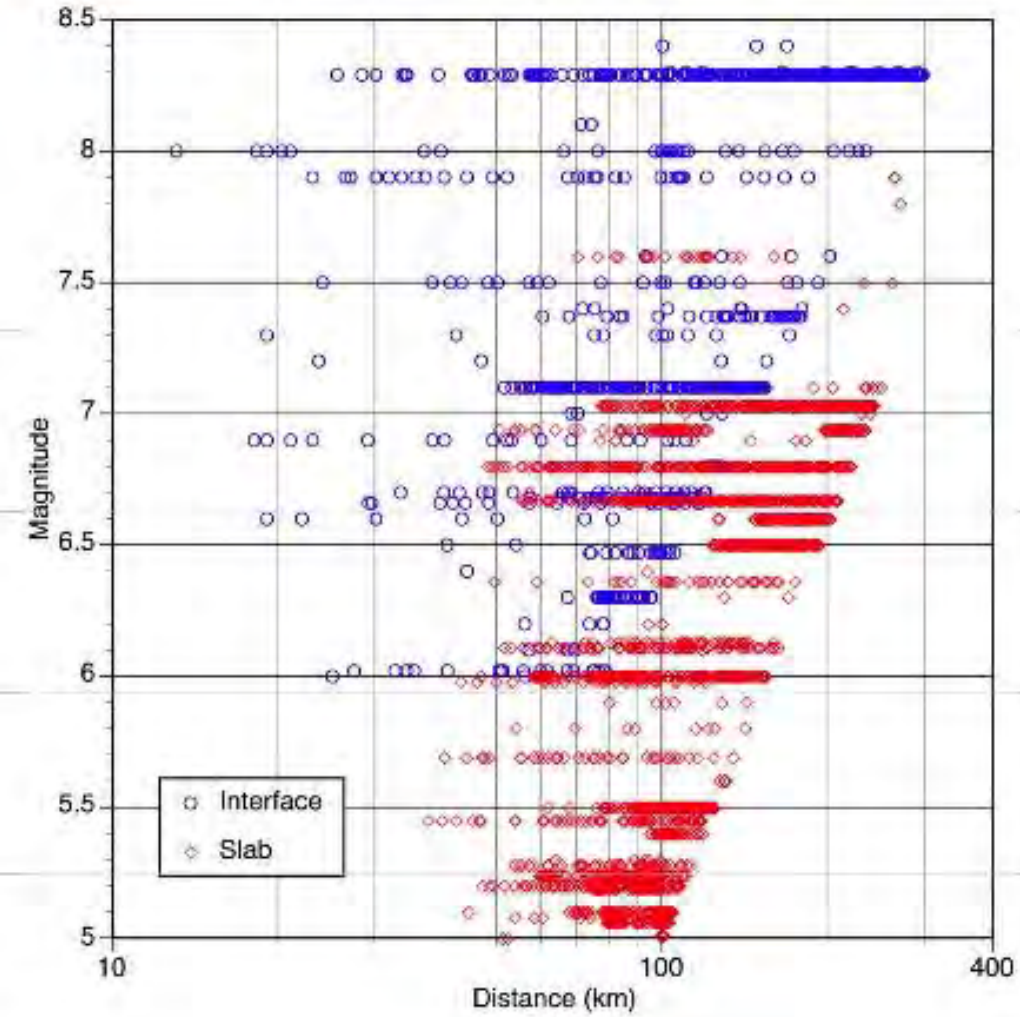
Issue: truncation of small amplitude data



BC hydro
FOR GENERATIONS

Final Dataset

BC hydro
FOR GENERATIONS



Slab:
63 earthquakes
2590 recordings

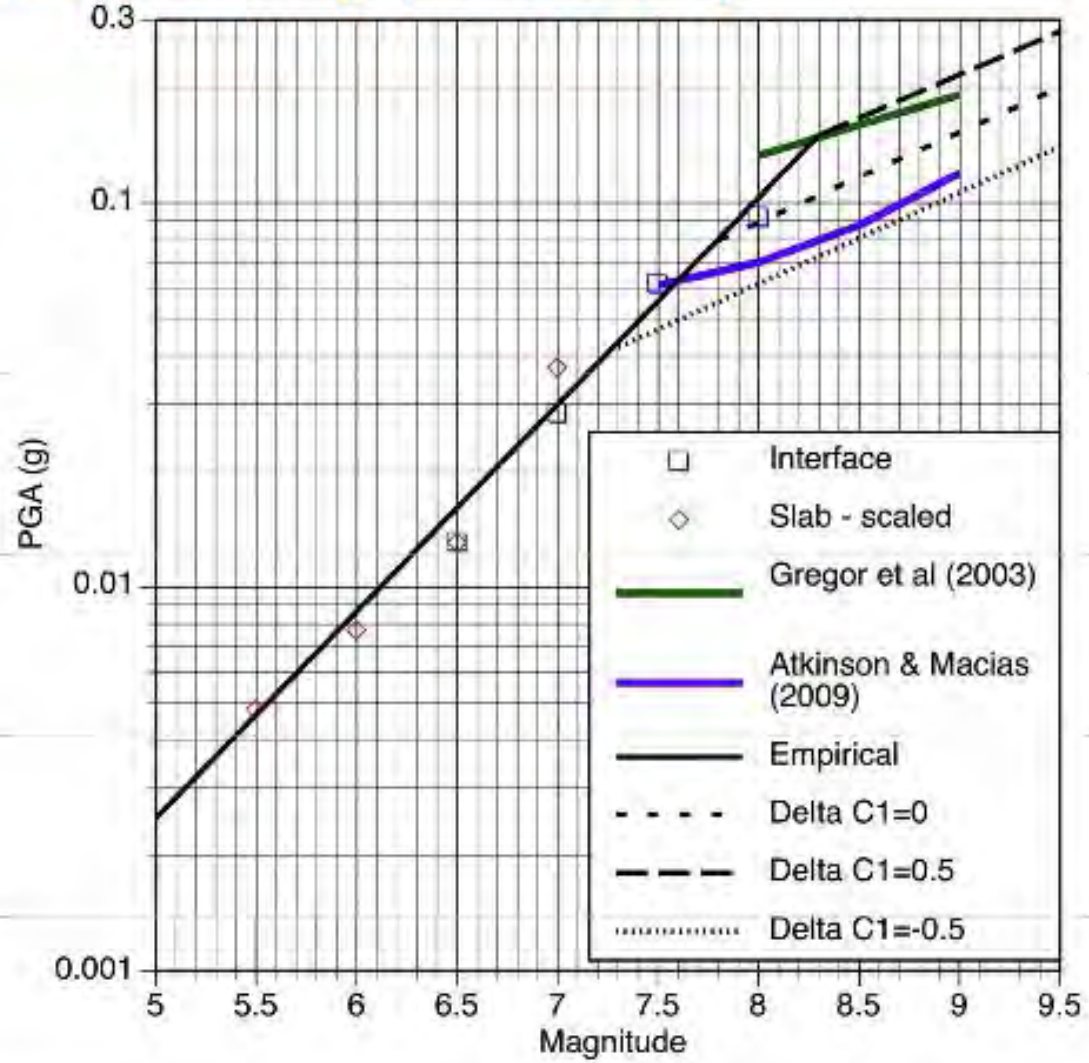
Interface:
43 earthquakes
960 recordings

Model Features

- Magnitude Scaling
  - Includes break in magnitude scaling at large magntiudes (C1) based on simulations
  - Revised based on 2010 Chile and 2011 Tohoku
- Depth
  - Only applies to slab events
- Site
  - VS30 with non-linear site response based on AS08 and CB08 NGA models (PEN range curves)
- Forearc/backarc
  - Includes different rates of attenuation for forearc and backarc sites
  - But mainly reflect Japan and may not be applicable to Cascadia
- Sigma
  - Both traditional and single-station sigema
- Epistemic Uncertainty
  - Includes range of constants to capture range of constant terms from different regions

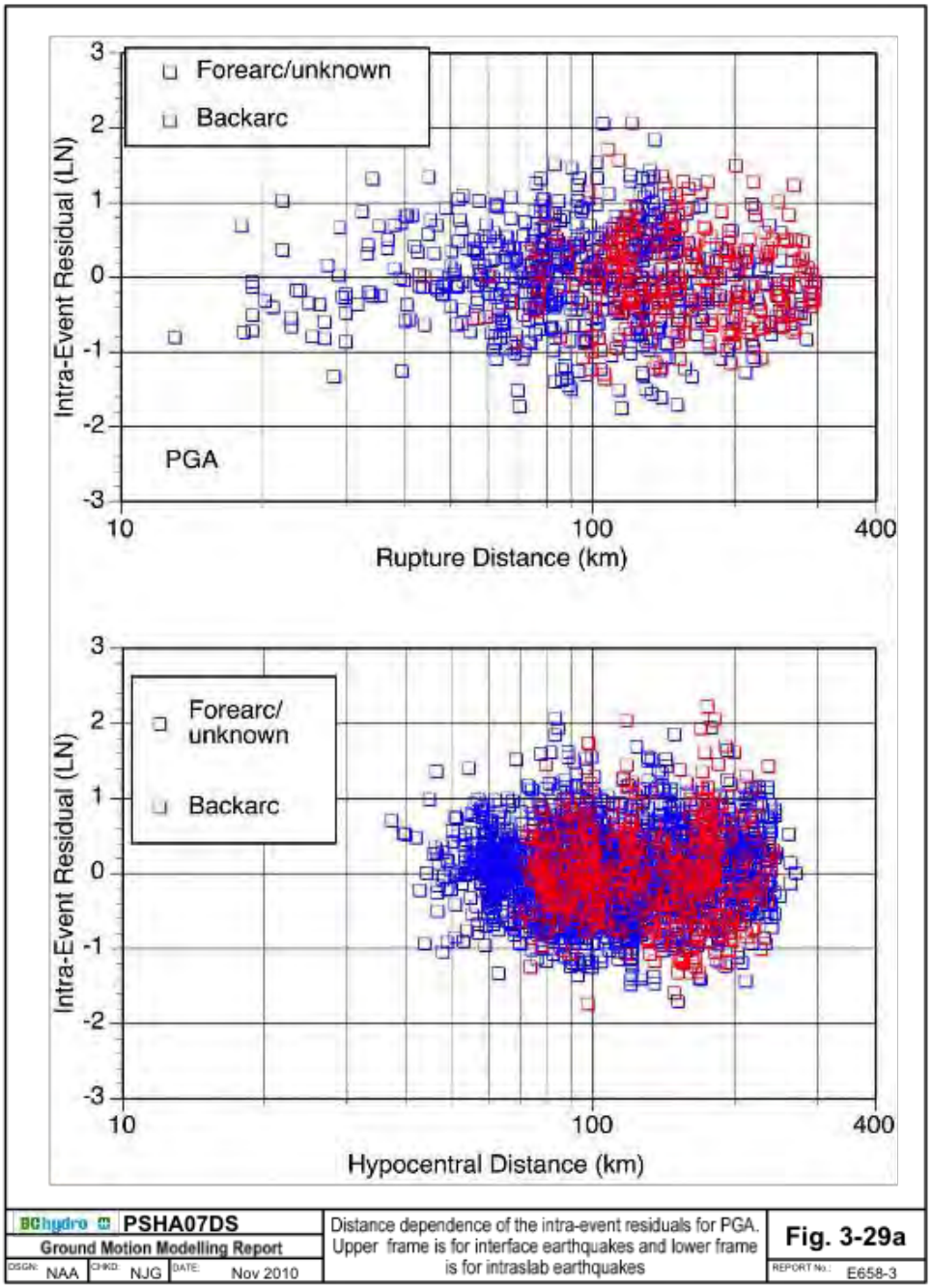
Magnitude Scaling (R=100 km)

BC hydro
FOR GENERATIONS



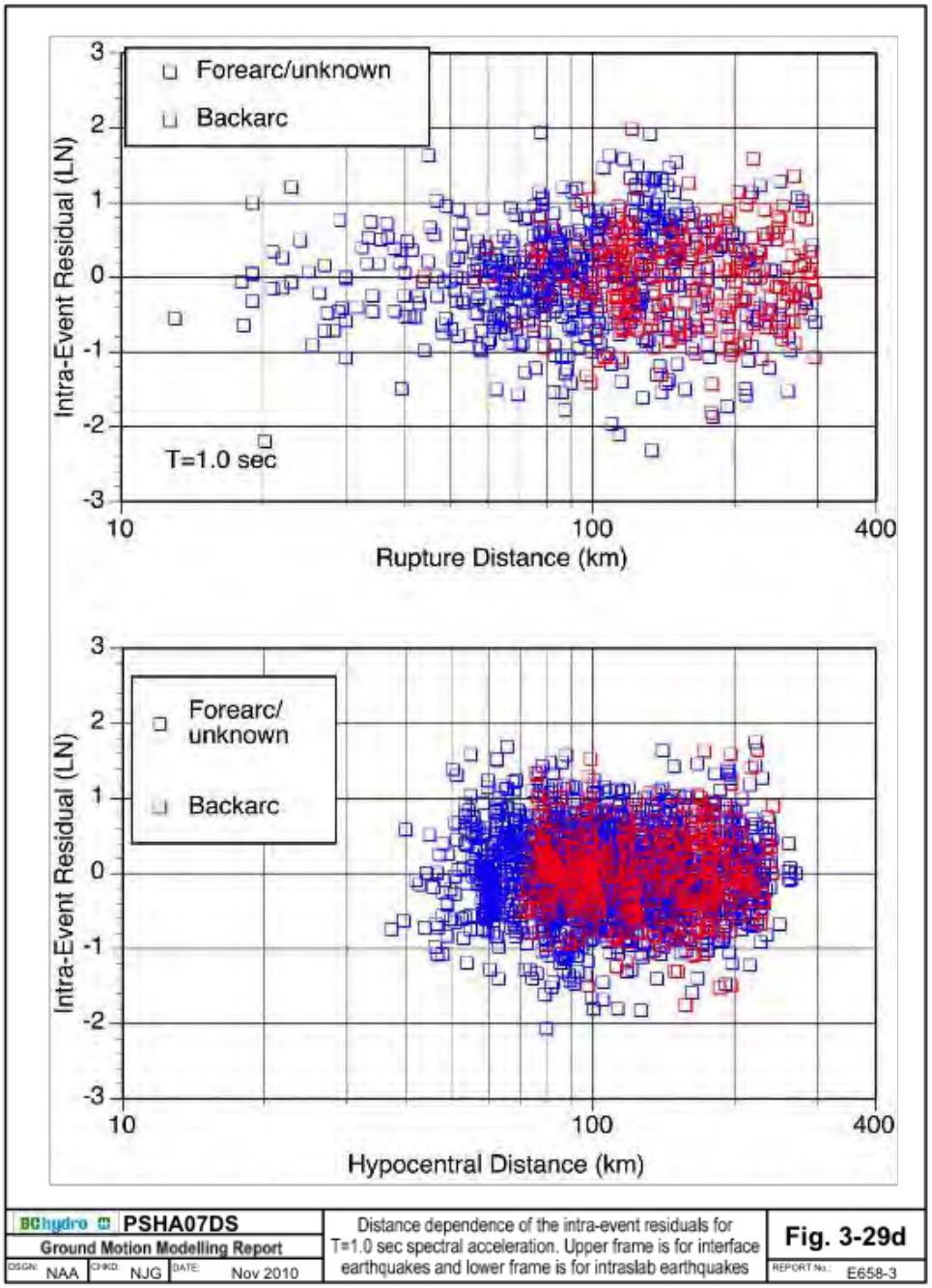
Interface

Slab

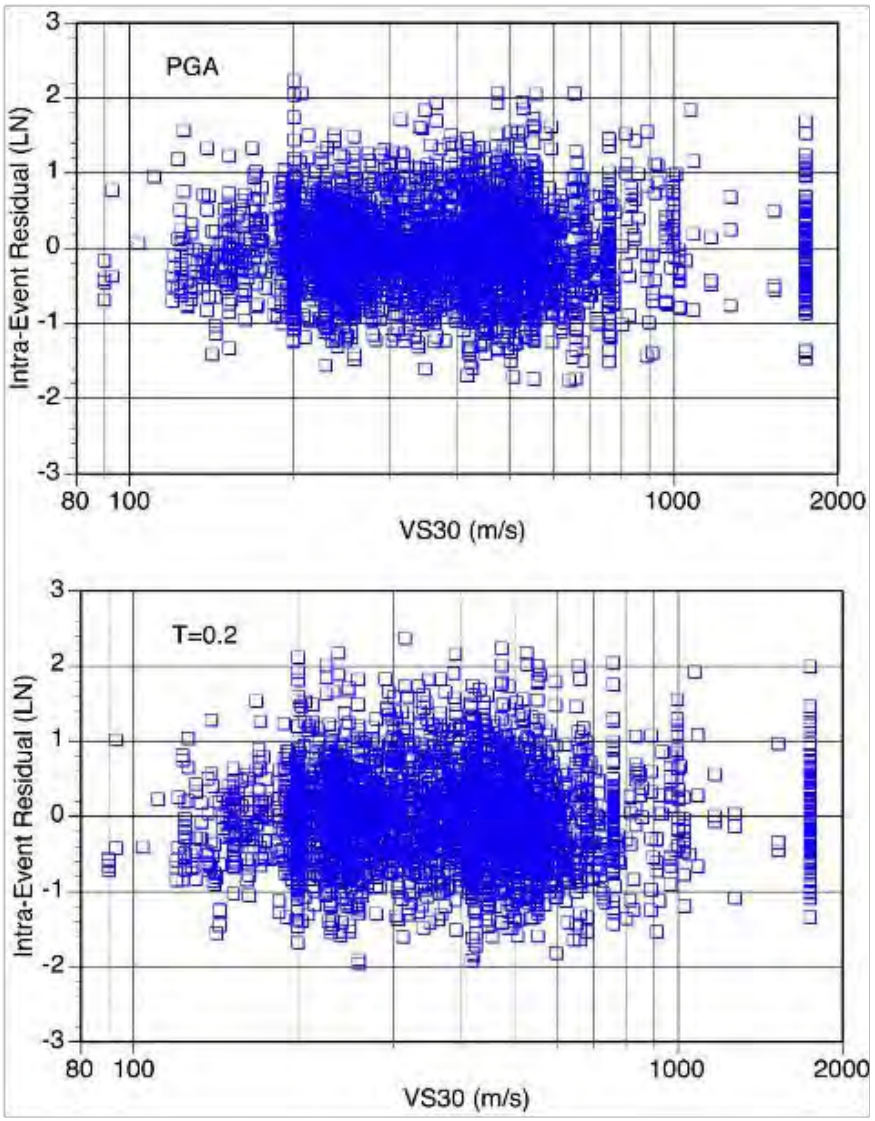


Interface

Slab



VS30

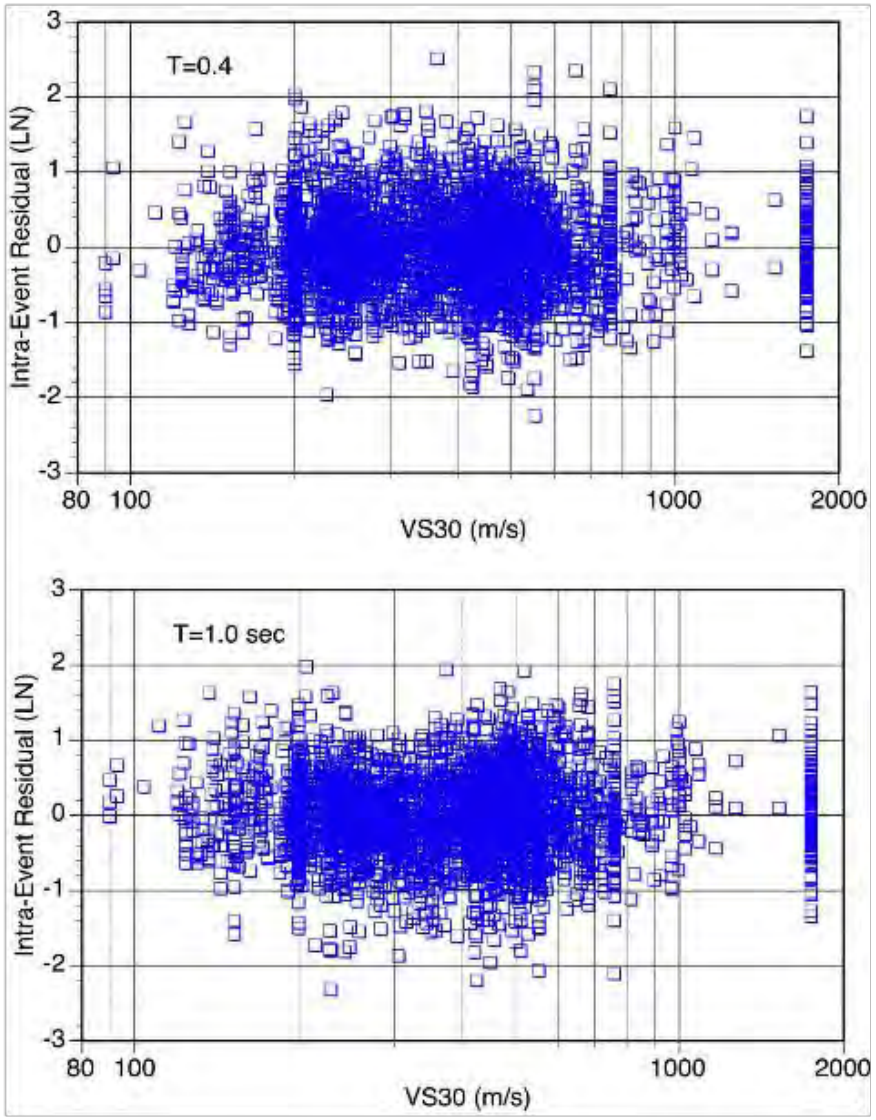


BC hydro | PSHA07DS
Ground Motion Modelling Report
DSGN: NAA | CHKD: NJG | DATE: Nov 2010

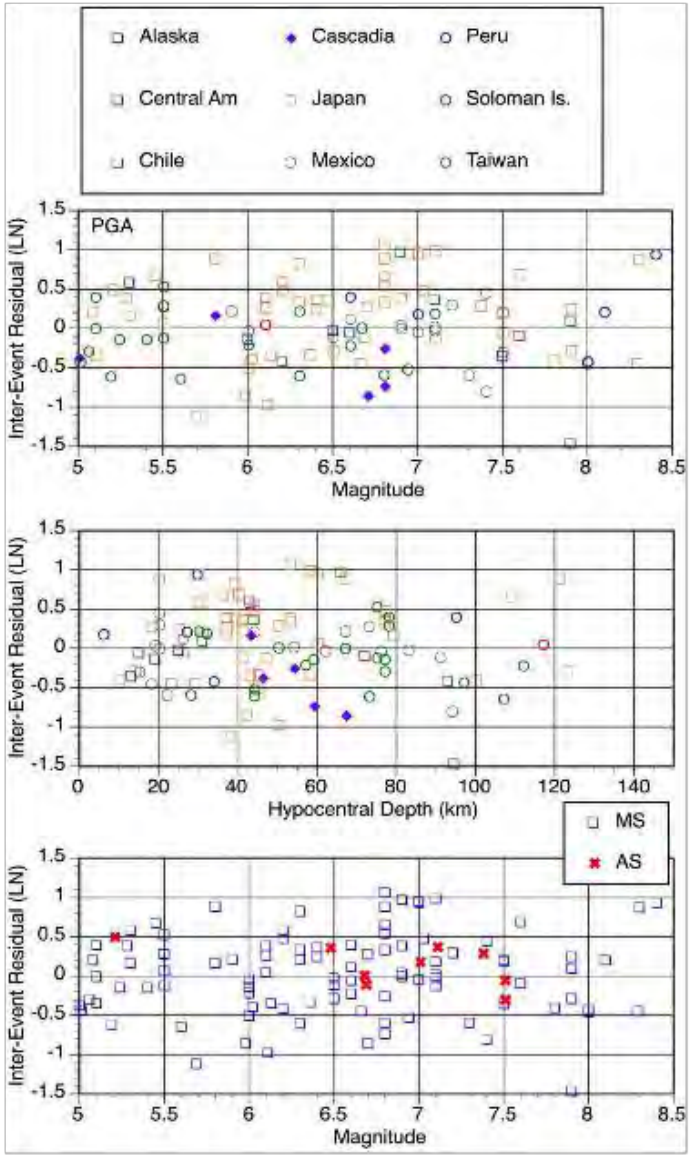
V_{S30} dependence of the intra-event residuals for PGA (top frame) and for spectral acceleration at T=0.2 sec (bottom frame)

Fig. 3-30a

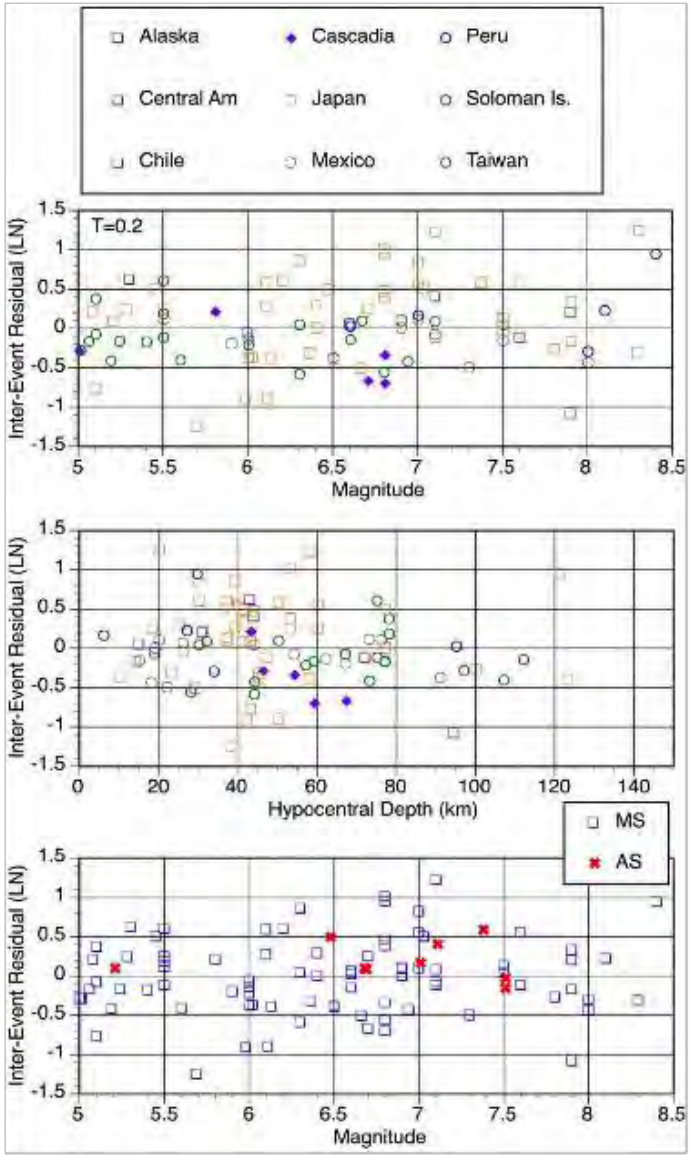
REPORT No.: E658-3



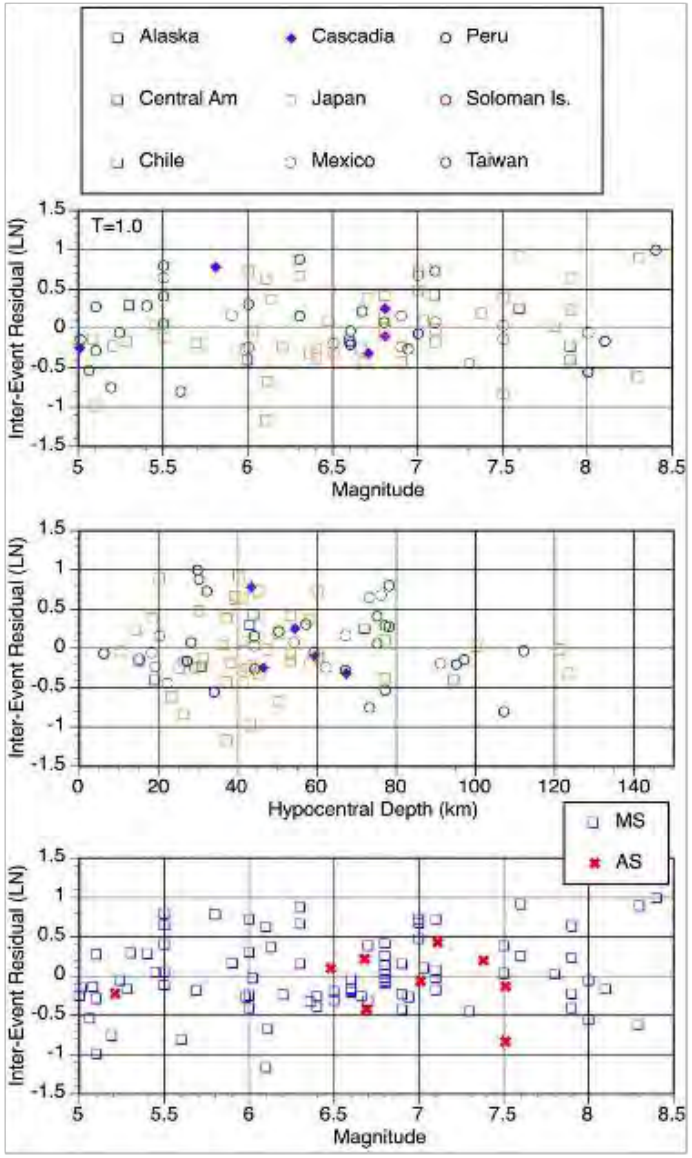
BC hydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	V_{S30} dependence of the intra-event residuals for spectral acceleration at T=0.4 sec (top frame) and T=1.0 sec (bottom frame)	Fig. 3-30b REPORT No.: E658-3



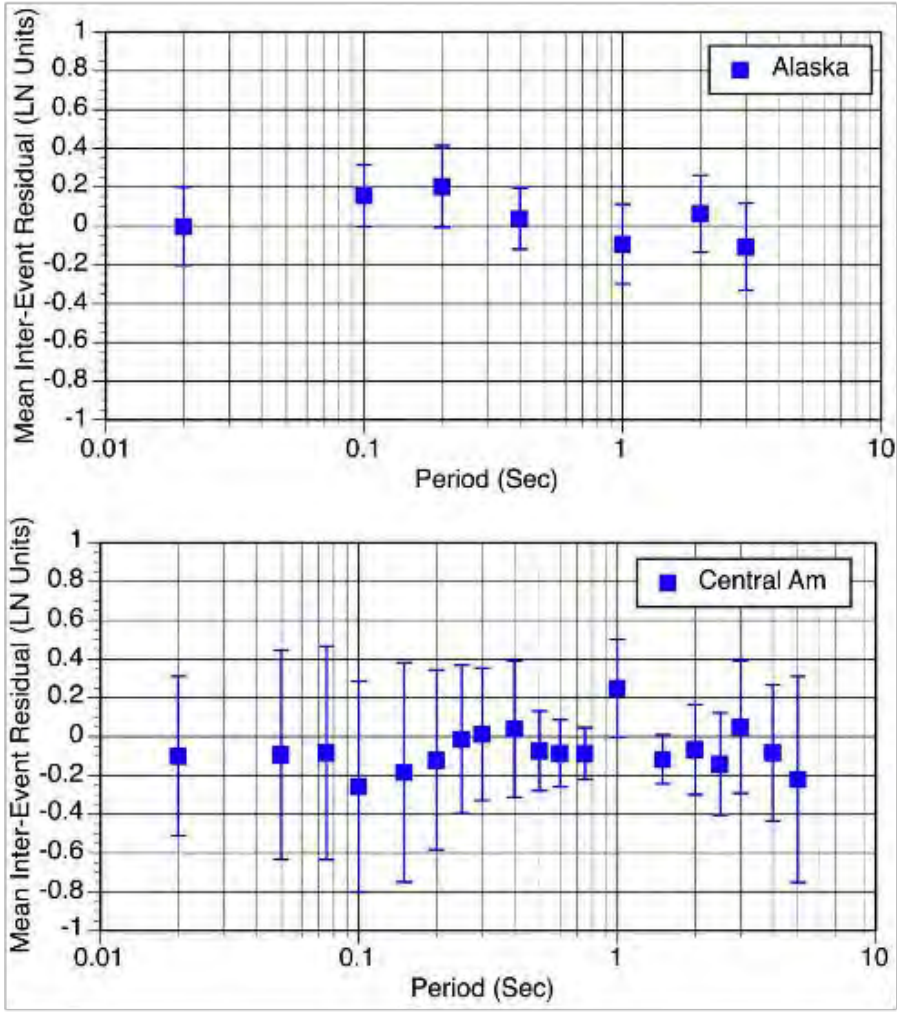
BCHydro PSHA07DS Ground Motion Modelling Report	Inter-event residuals for PGA		Fig. 3-25a
DSGN: NAA CHKD: NJG DATE: Nov 2010			REPORT No.: E658-3



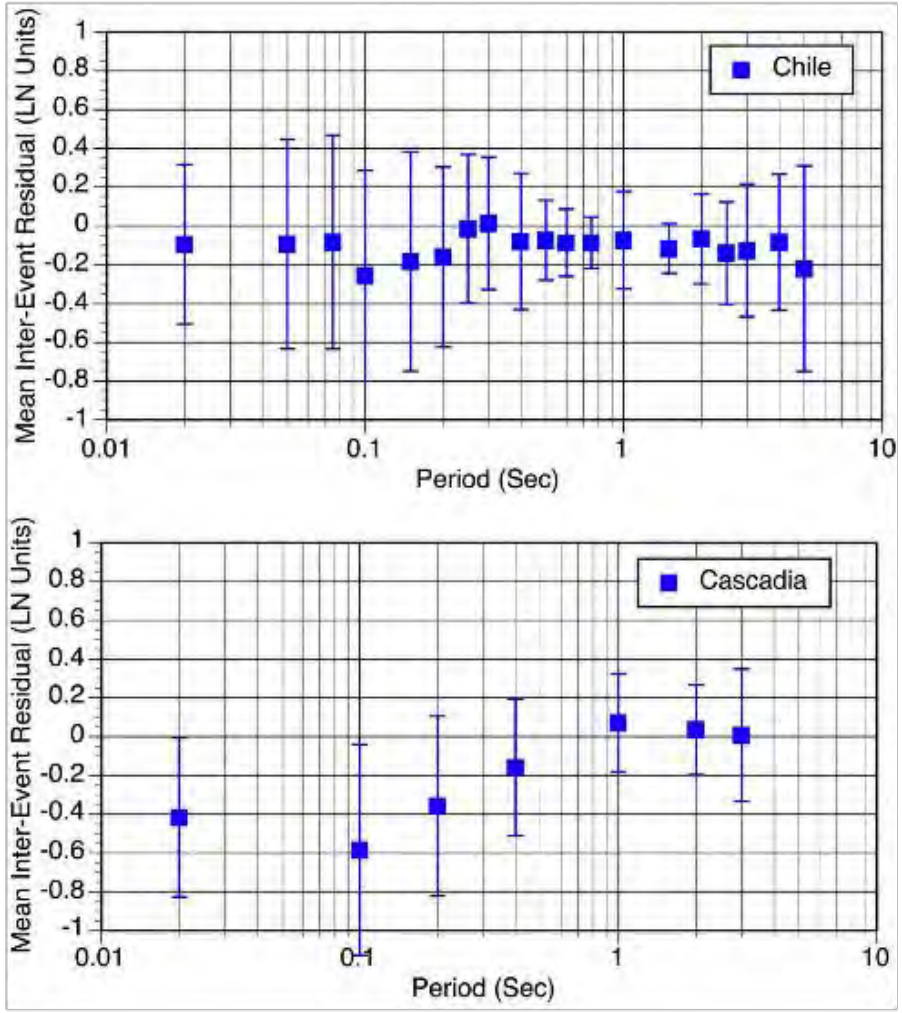
BCHydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	Inter-event residuals for T=0.2 sec spectral acceleration	**Fig. 3-25b** REPORT No.: E658-3



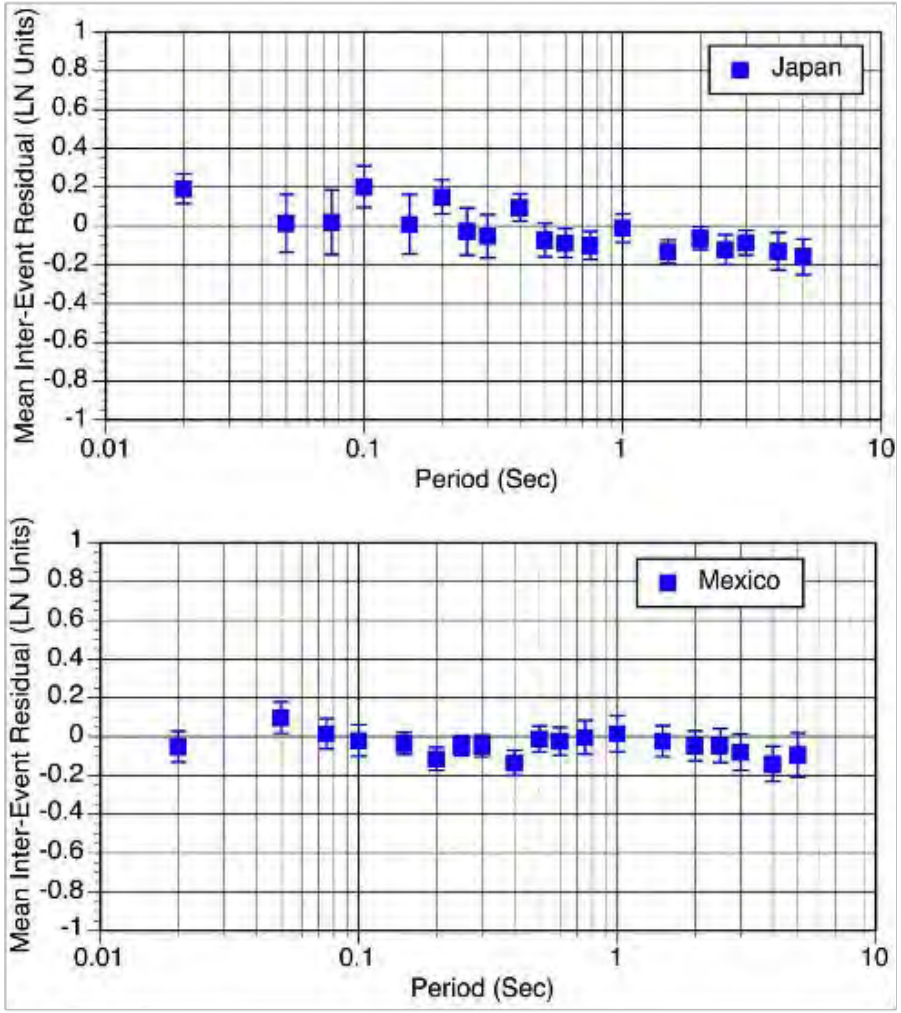
BC hydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	Inter-event residuals for T=1.0 sec spectral acceleration	**Fig. 3-25d** REPORT No.: E658-3



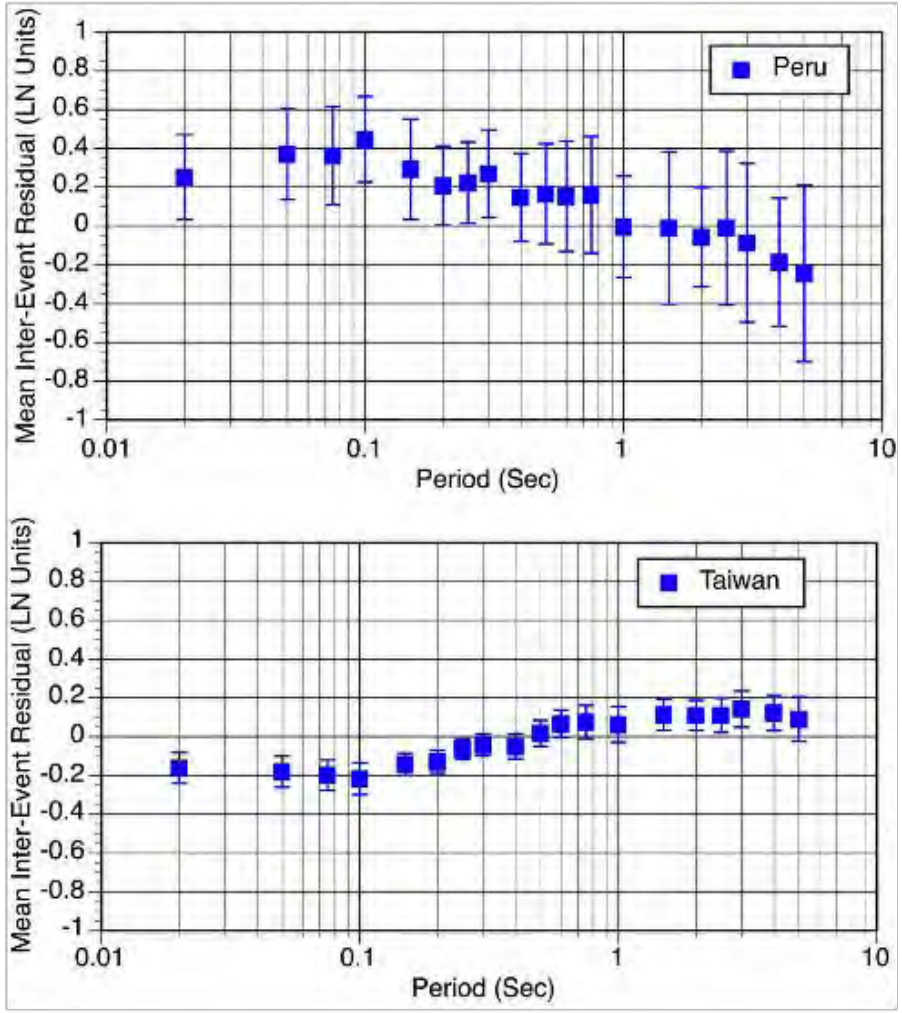
BCHydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	Average inter-event residual by region	Fig. 3-26a REPORT No.: E658-3



BC hydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	Average inter-event residual by region	**Fig. 3-26b** REPORT No.: E658-3

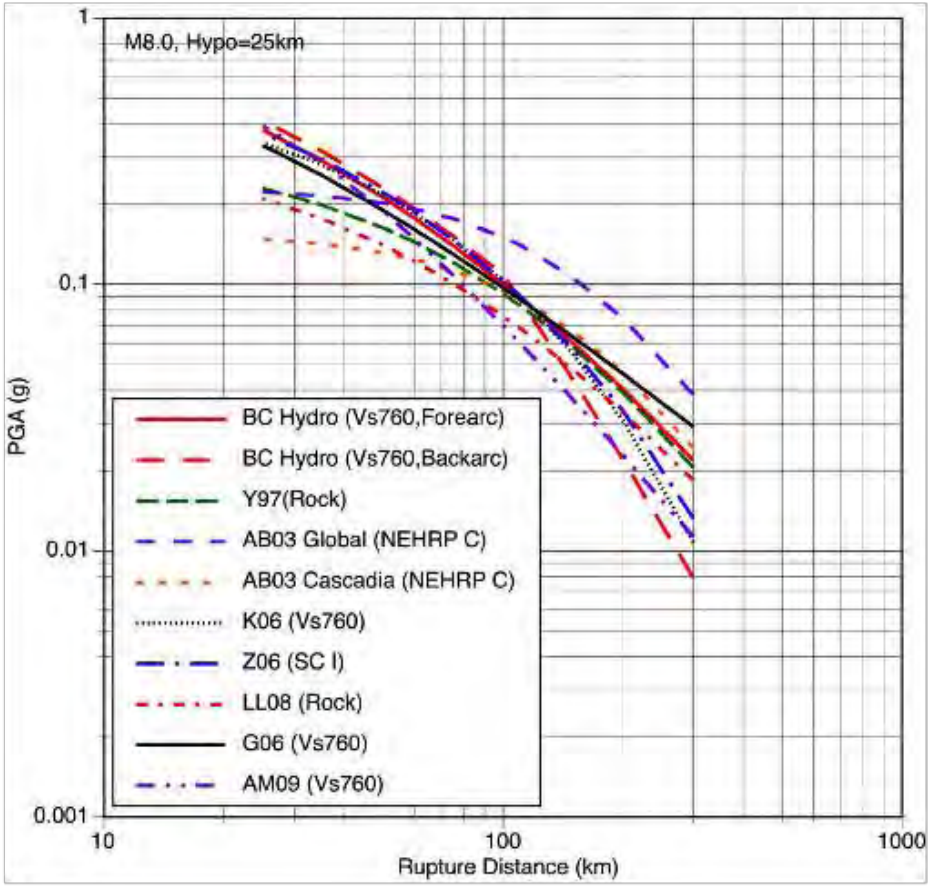


BCHydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	Average inter-event residual by region	Fig. 3-26c REPORT No.: E658-3



BC hydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	Average inter-event residual by region	Fig. 3-26d REPORT No.: E658-3

Interface
M=8

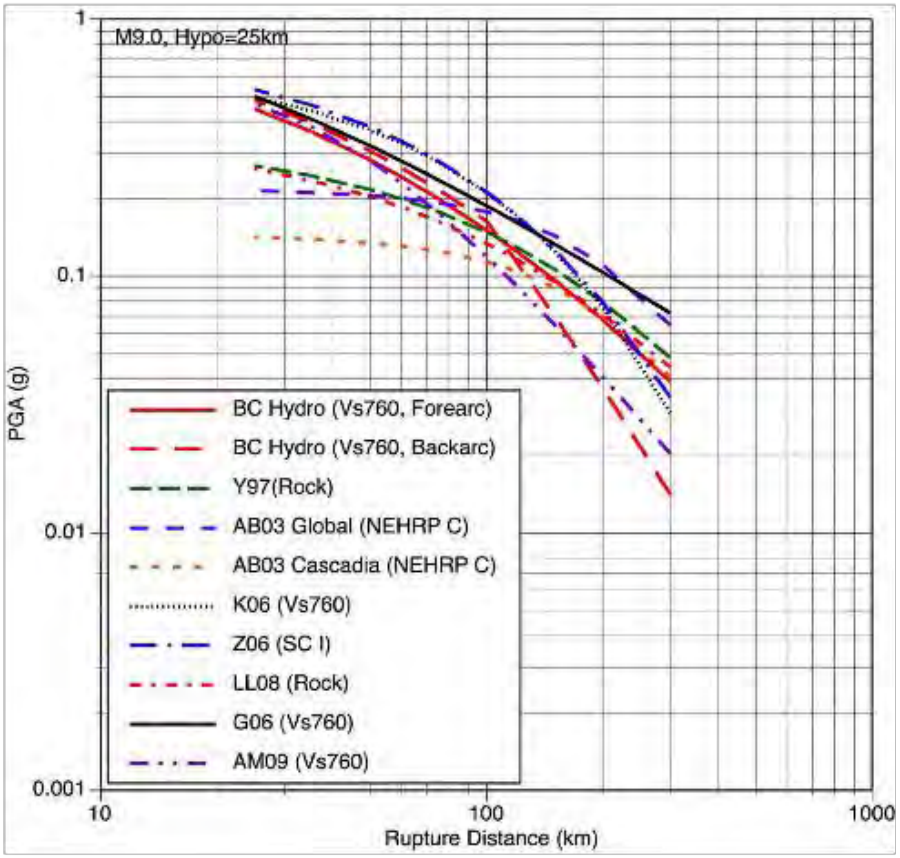


BC hydro | PSHA07DS
Ground Motion Modelling Report
DSGN: NAA | CHKD: NJG | DATE: Nov 2010

PGA attenuation for M8 interface earthquakes

Fig. 3-32
REPORT No.: E658-3

Interface
M=9

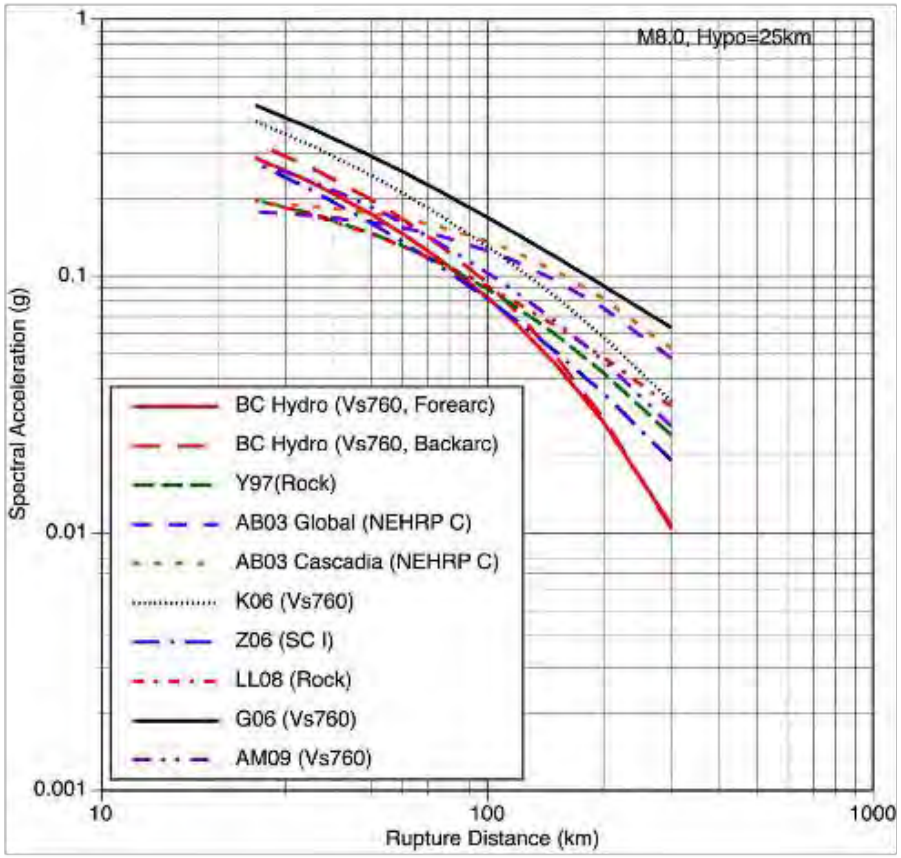


BC hydro | PSHA07DS
Ground Motion Modelling Report
DSGN: NAA | CHKD: NJG | DATE: Nov 2010

PGA attenuation for M9 interface earthquakes

Fig. 3-33
REPORT No.: E658-3

Interface
M=8

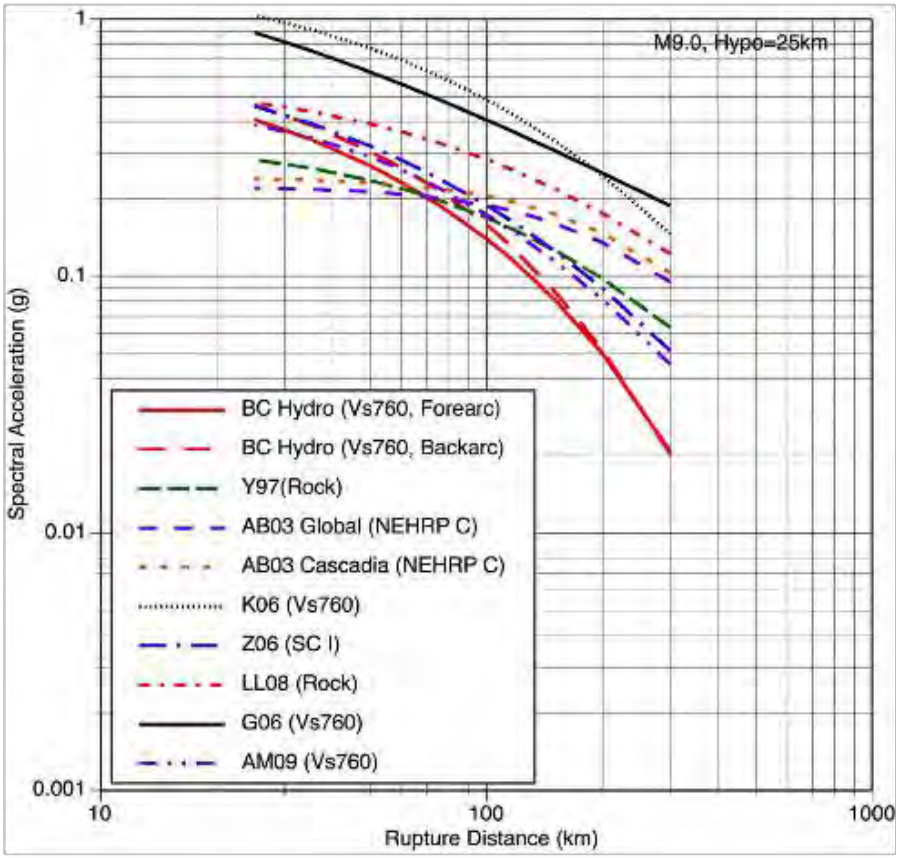


BC hydro | PSHA07DS
Ground Motion Modelling Report
DSGN: NAA | CHKD: NJG | DATE: Nov 2010

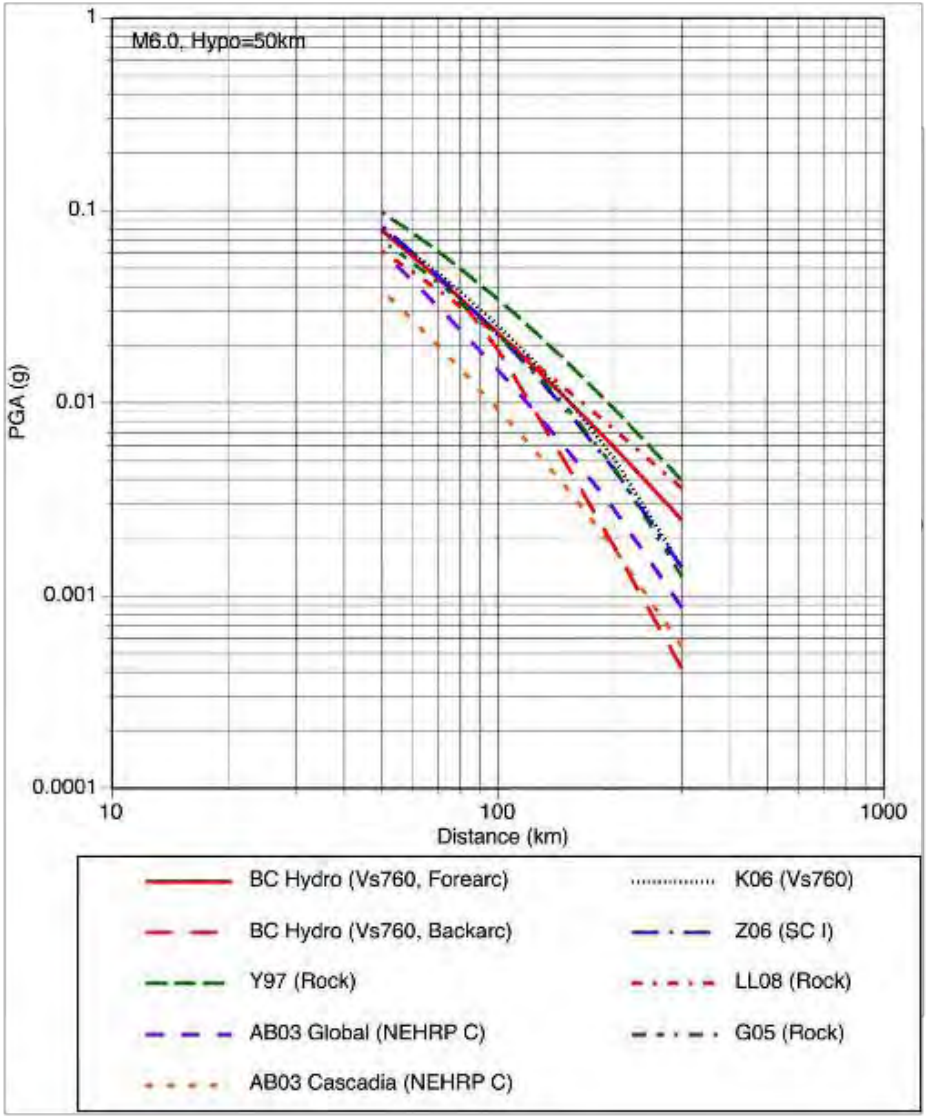
T=1 sec attenuation for M8 interface earthquakes

Fig. 3-34
REPORT No.: E658-3

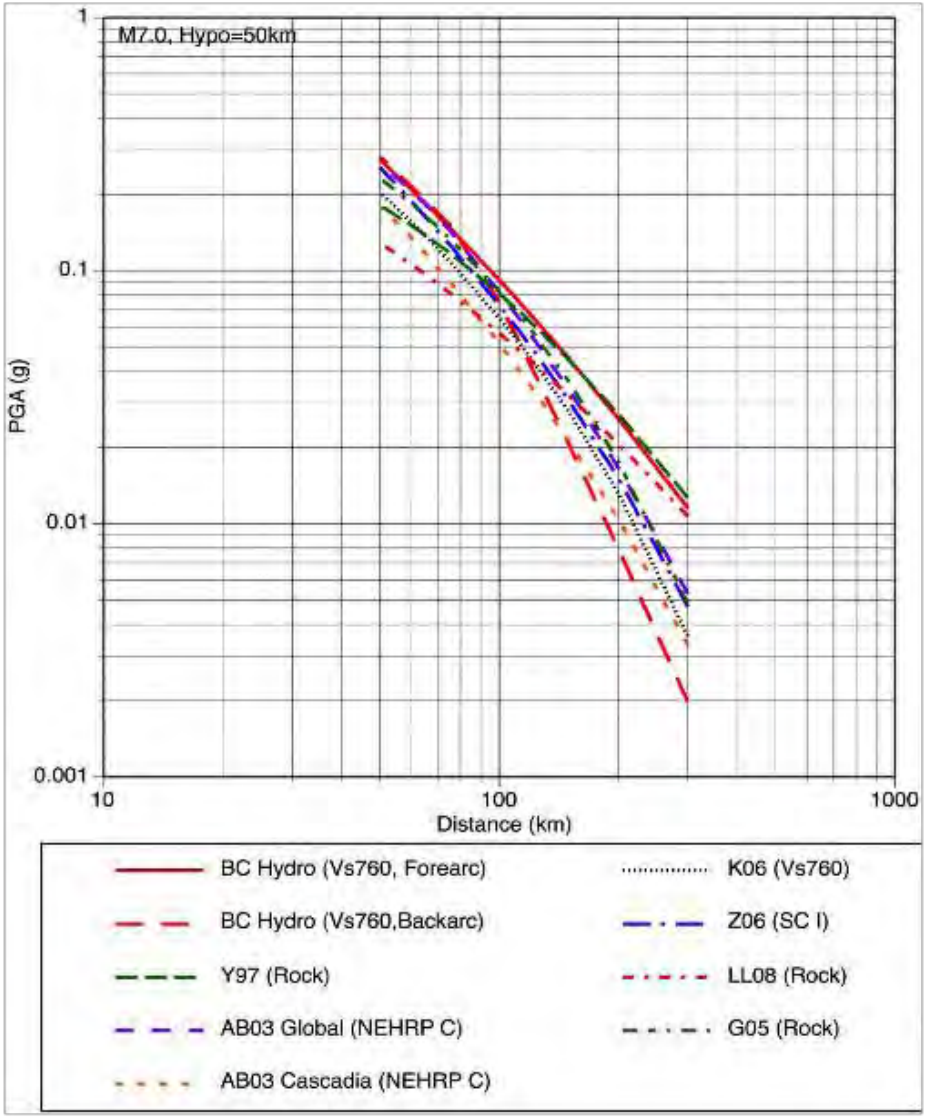
Interface
M=9



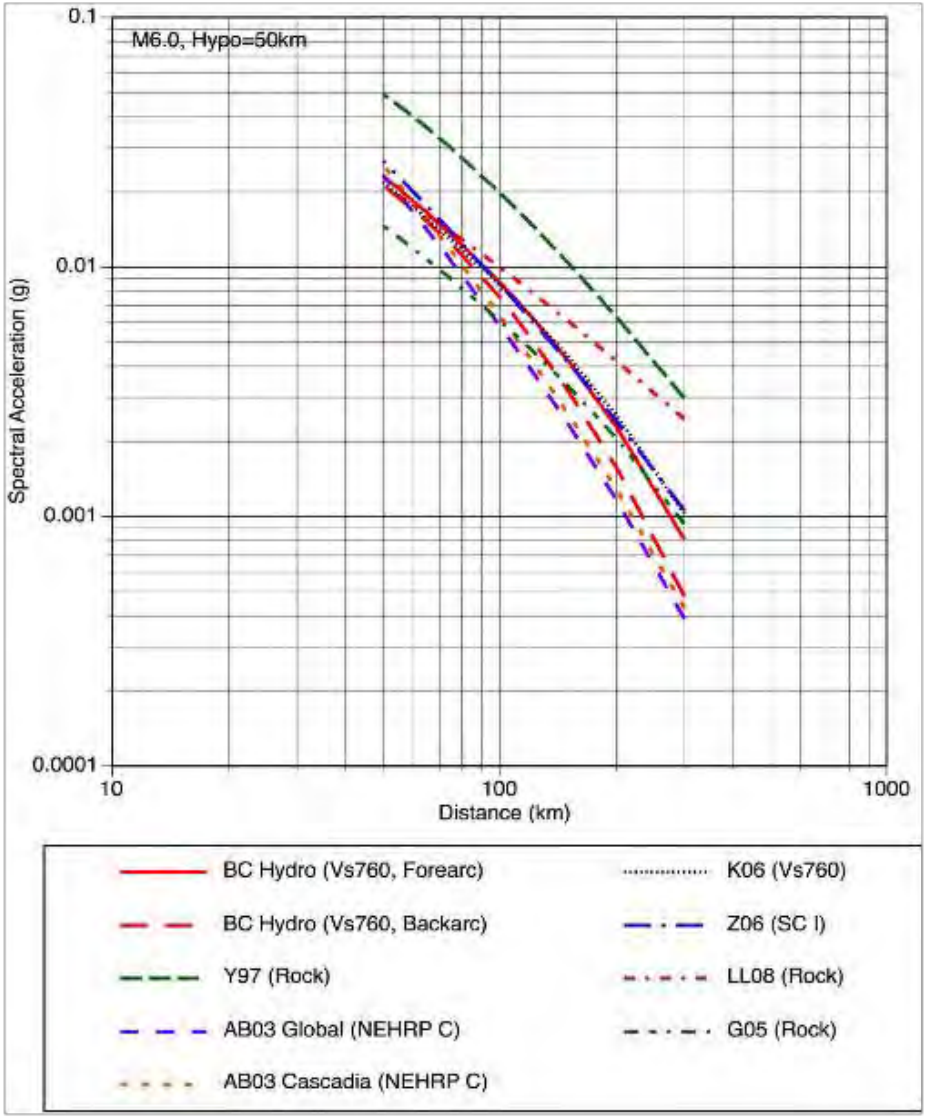
BC Hydro	PSHA07DS			T=1 sec attenuation for M9 interface earthquakes	Fig. 3-35
Ground Motion Modelling Report					REPORT No.: E658-3
DSGN: NAA	CHKD: NJG	DATE: Nov 2010			



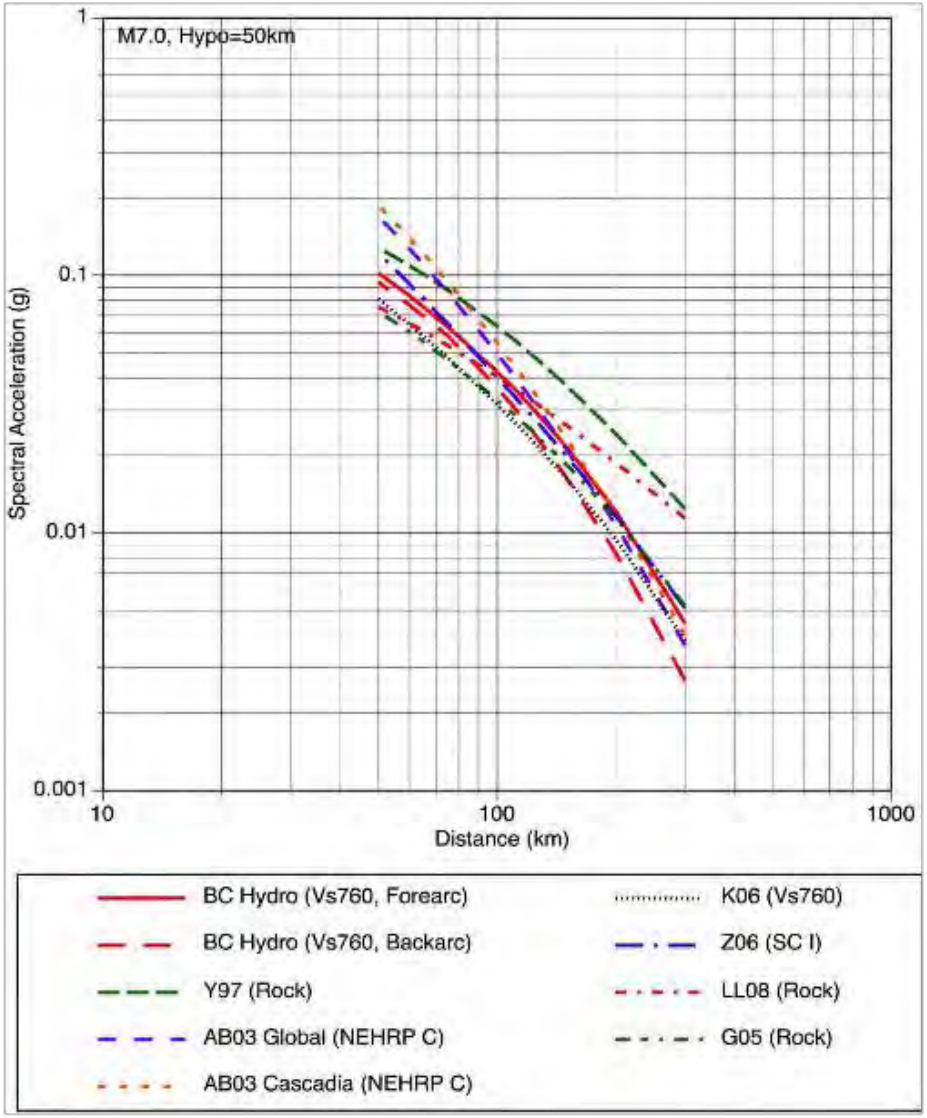
BC hydro PSHA07DS Ground Motion Modelling Report	Distance scaling of the median spectra for interface earthquakes for Backarc station locations and C1=0.0	Figure 3-33b
DSGN: NAA CHKD: NJG DATE: Nov 2010	PGA attenuation for M6 intraslab events	REPORT No.: E658-3



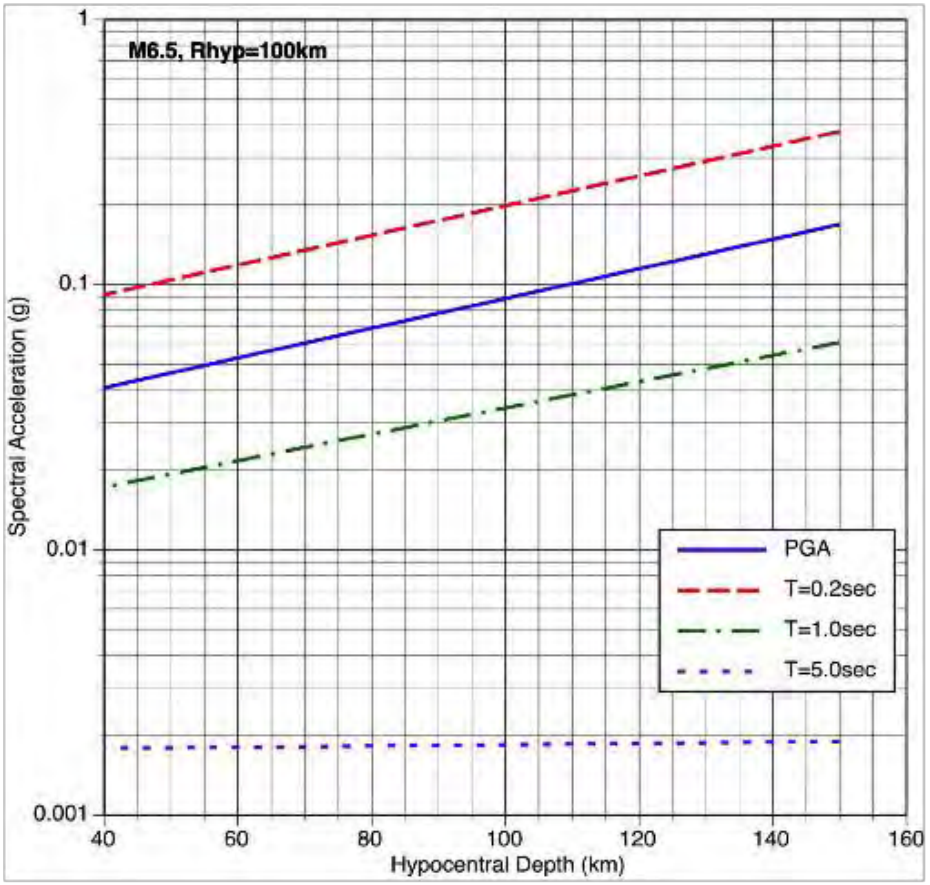
BC hydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	PGA attenuation for M7 intraslab events	Fig. 3-39 REPORT No.: E658-3



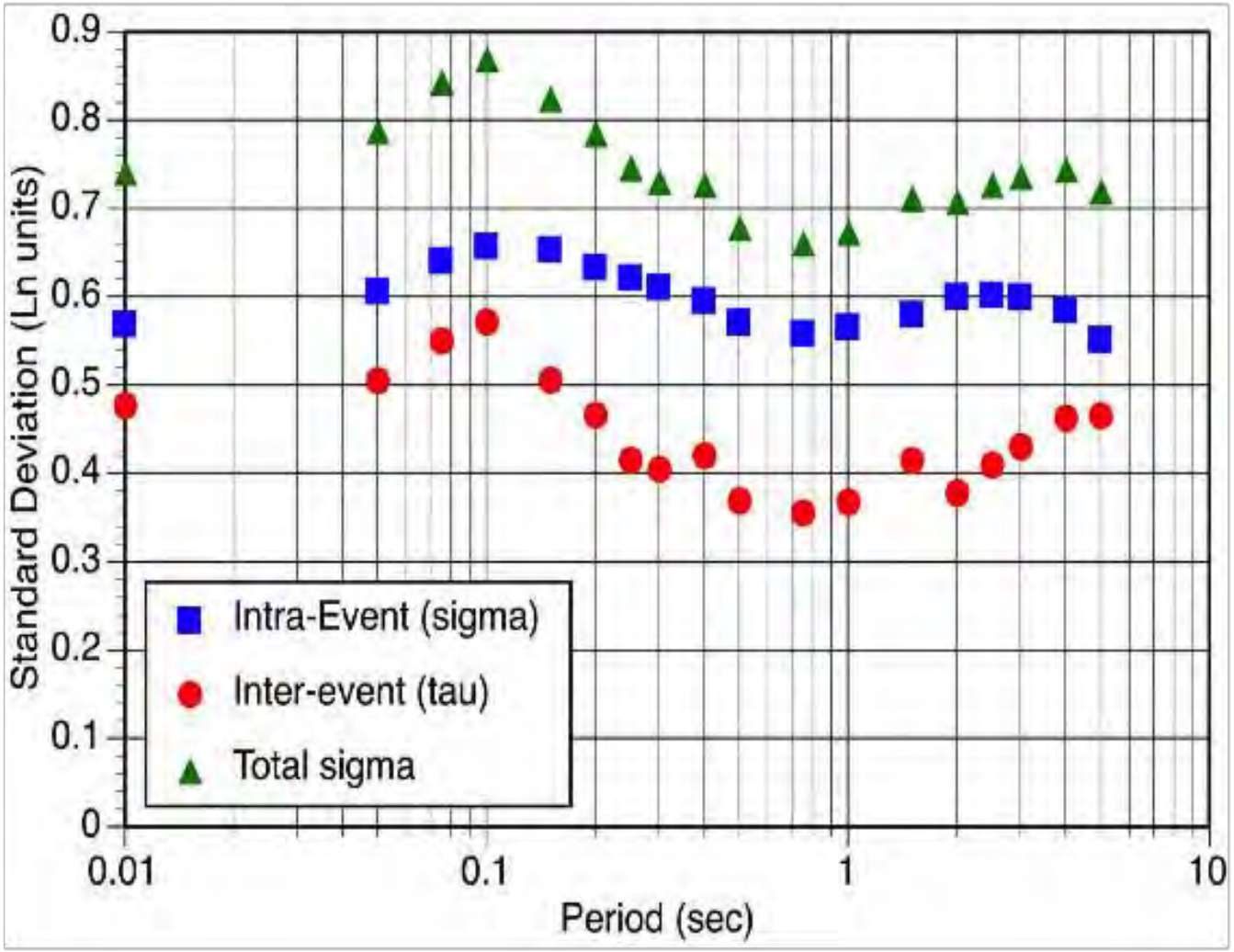
BC hydro	PSHA07DS				
Ground Motion Modelling Report					
DSGN: NAA	CHKD: NJG	DATE: Nov 2010	T=1 sec spectral attenuation for M6 intraslab events	Fig. 3-40	
				REPORT No.: E658-3	



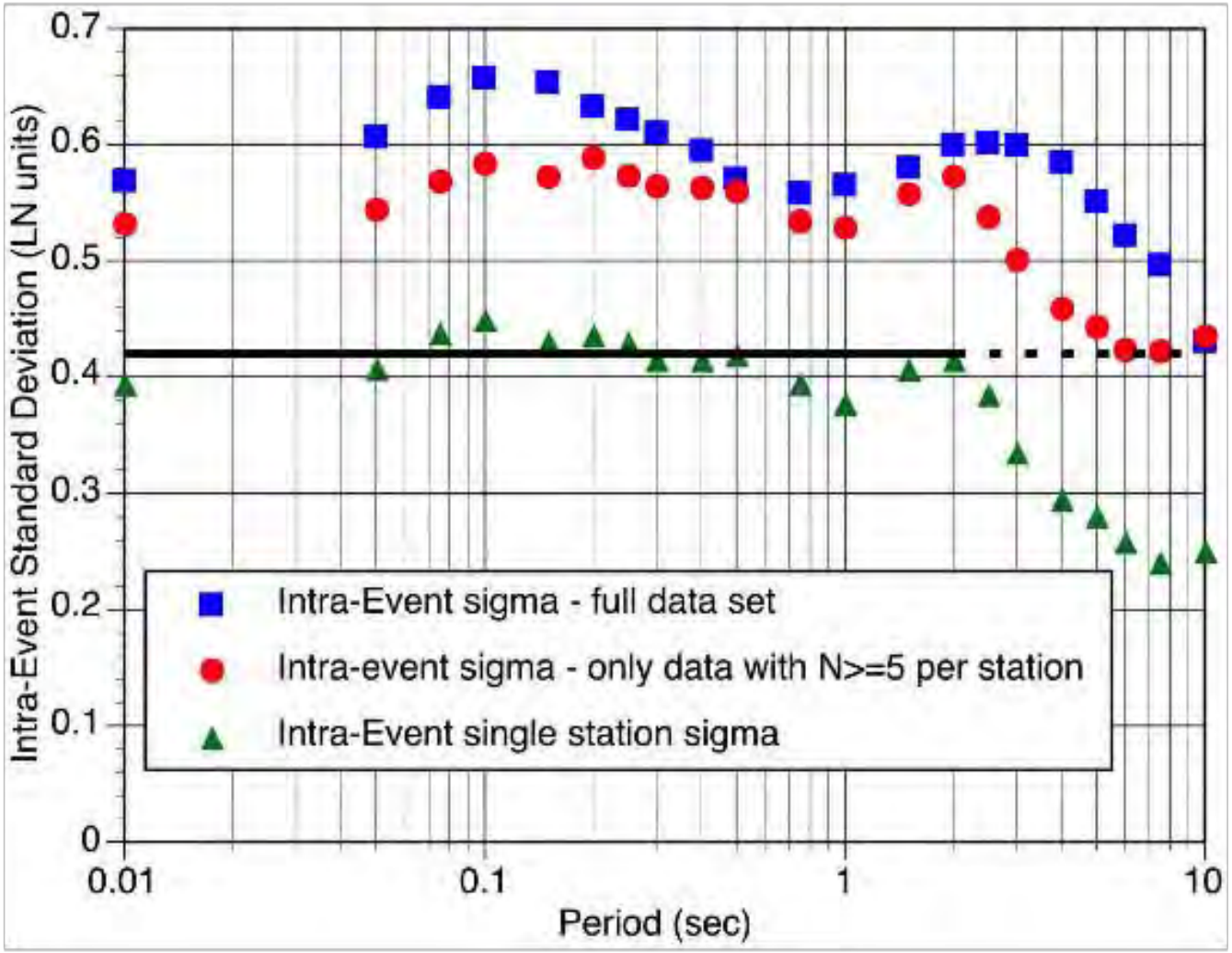
BChydro PSHA07DS Ground Motion Modelling Report	T=1 sec spectral attenuation for M7 intraslab events		Fig. 3-41
DSGN: NAA CHKD: NJG DATE: Nov 2010			REPORT No.: E658-3



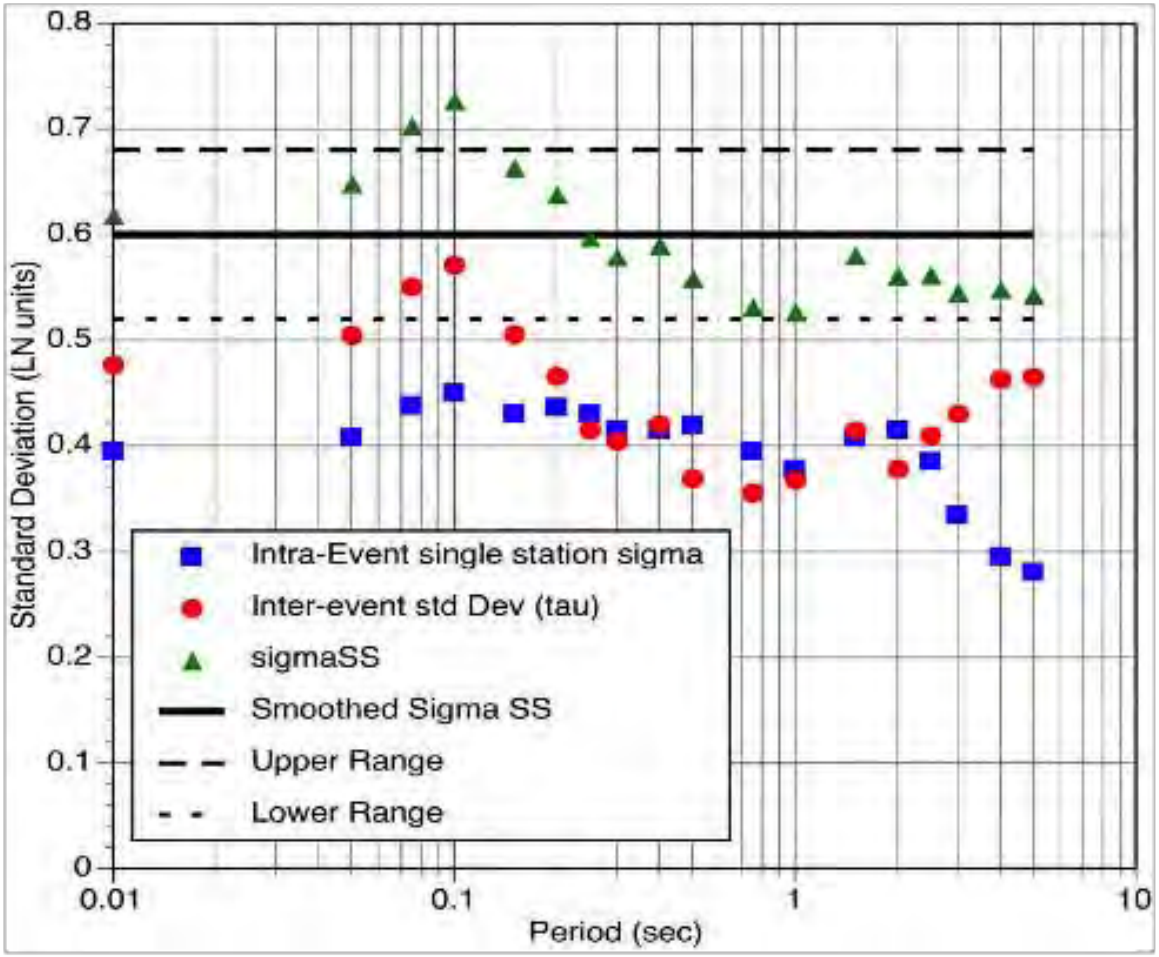
BC hydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	Hypocentral depth dependence for PGA and spectral periods of 0.2, 1.0, and 5.0 seconds from a magnitude 6.5 earthquake at a hypocentral distance of 100 km for Forearc site locations	**Fig. 3-44**	REPORT No.: E658-3



BChydro PSHA07DS Ground Motion Modelling Report	DATE: Nov 2010 DSGN: NAA CHK: NJG REPORT No.: E658-3	Inter-event, intra-event, and total standard deviations (not single-station)	Fig. 3-47

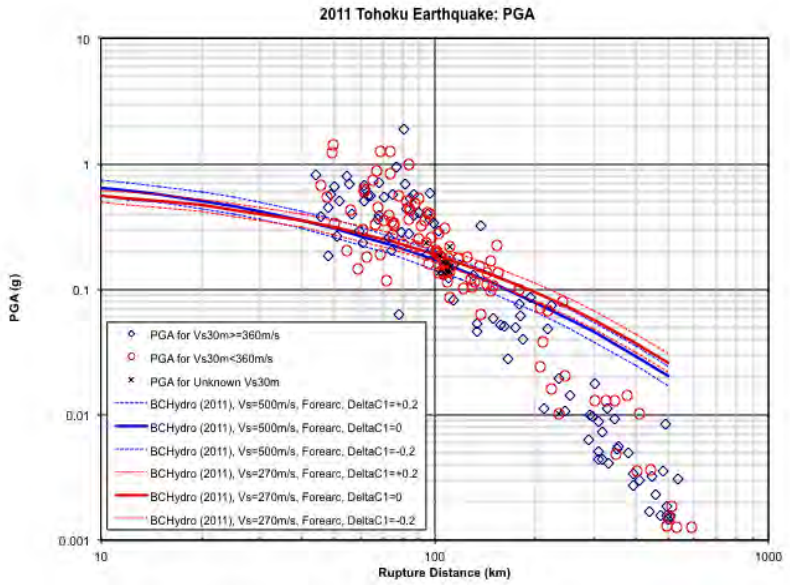


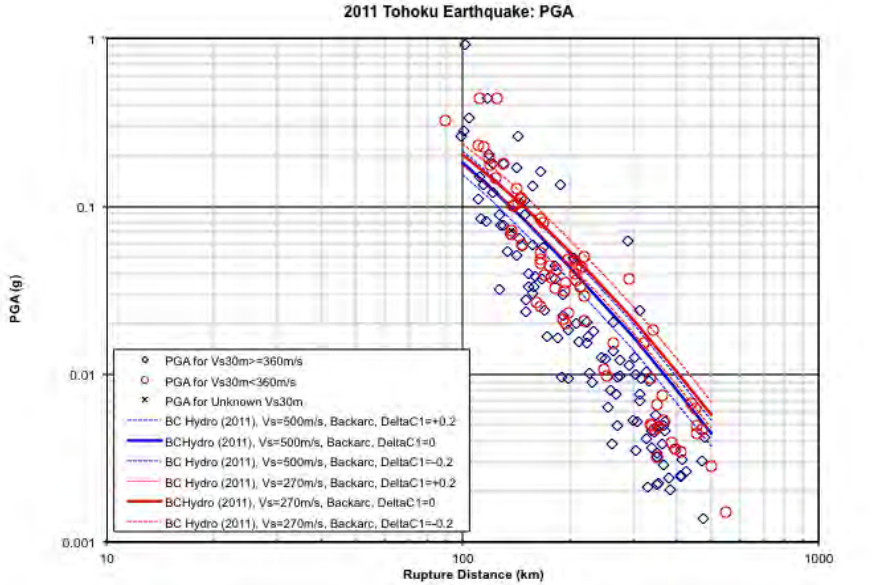
BChydro PSHA07DS Ground Motion Modelling Report	DATE: Nov 2010 DSGN: NAA CHK: NJG REPORT No.: E658-3	Comparison of the Intra-event standard deviation with the single-station intra-event standard deviation	Fig. 3-48



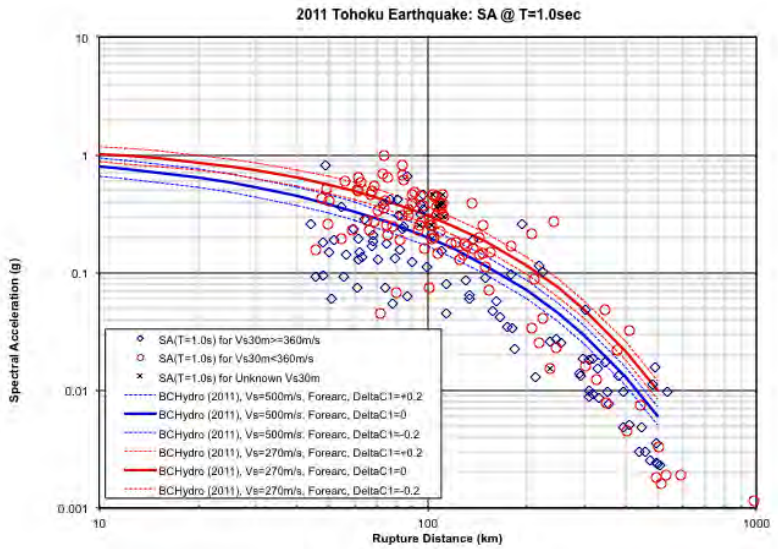
BCHydro PSHA07DS Ground Motion Modelling Report	DATE: Nov 2010 DSGN: NAA CHK: NJG REPORT No.: E658-3	Total single-station standard deviations	Fig. 3-49

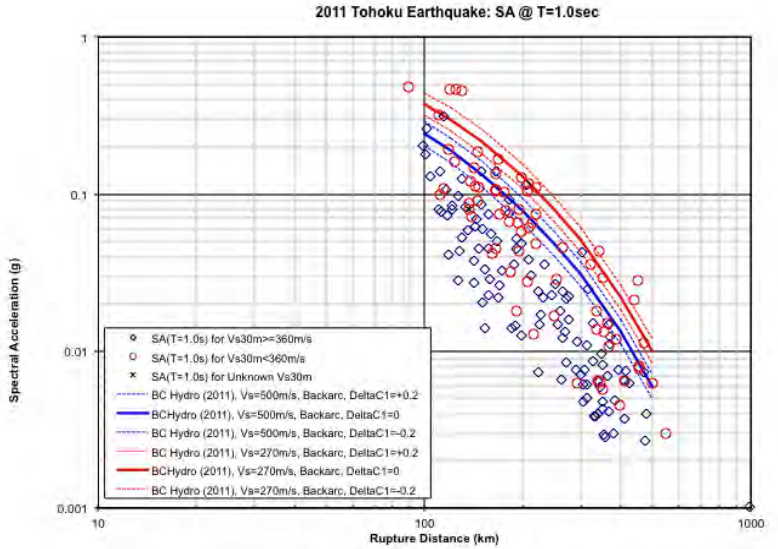
Tohoku (PGA)


2011 Tohoku Earthquake: PGA
PGA (g)
Rupture Distance (km)
PGA for Vs30m>=360m/s
PGA for Vs30m<360m/s
PGA for Unknown Vs30m
BCHydro (2011), Vs=500m/s, Forearc, DeltaC1=+0.2
BCHydro (2011), Vs=500m/s, Forearc, DeltaC1=0
BCHydro (2011), Vs=500m/s, Forearc, DeltaC1=-0.2
BCHydro (2011), Vs=270m/s, Forearc, DeltaC1=+0.2
BCHydro (2011), Vs=270m/s, Forearc, DeltaC1=0
BCHydro (2011), Vs=270m/s, Forearc, DeltaC1=-0.2

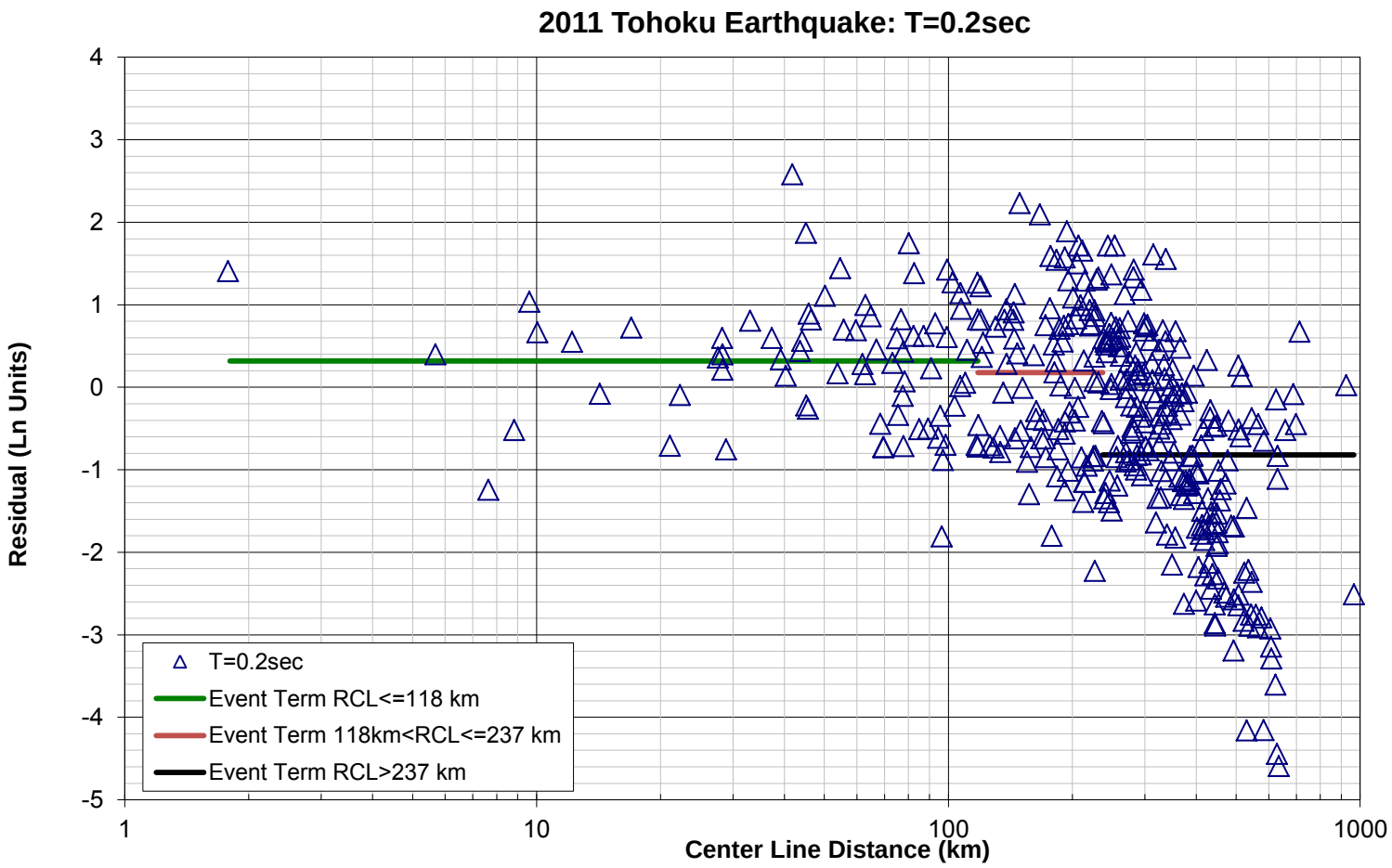

2011 Tohoku Earthquake: PGA
PGA (g)
Rupture Distance (km)
PGA for Vs30m>=360m/s
PGA for Vs30m<360m/s
PGA for Unknown Vs30m
BC Hydro (2011), Vs=500m/s, Backarc, DeltaC1=+0.2
BCHydro (2011), Vs=500m/s, Backarc, DeltaC1=0
BC Hydro (2011), Vs=500m/s, Backarc, DeltaC1=-0.2
BC Hydro (2011), Vs=270m/s, Backarc, DeltaC1=+0.2
BCHydro (2011), Vs=270m/s, Backarc, DeltaC1=0
BC Hydro (2011), Vs=270m/s, Backarc, DeltaC1=-0.2

Tohoku (T=1 sec)

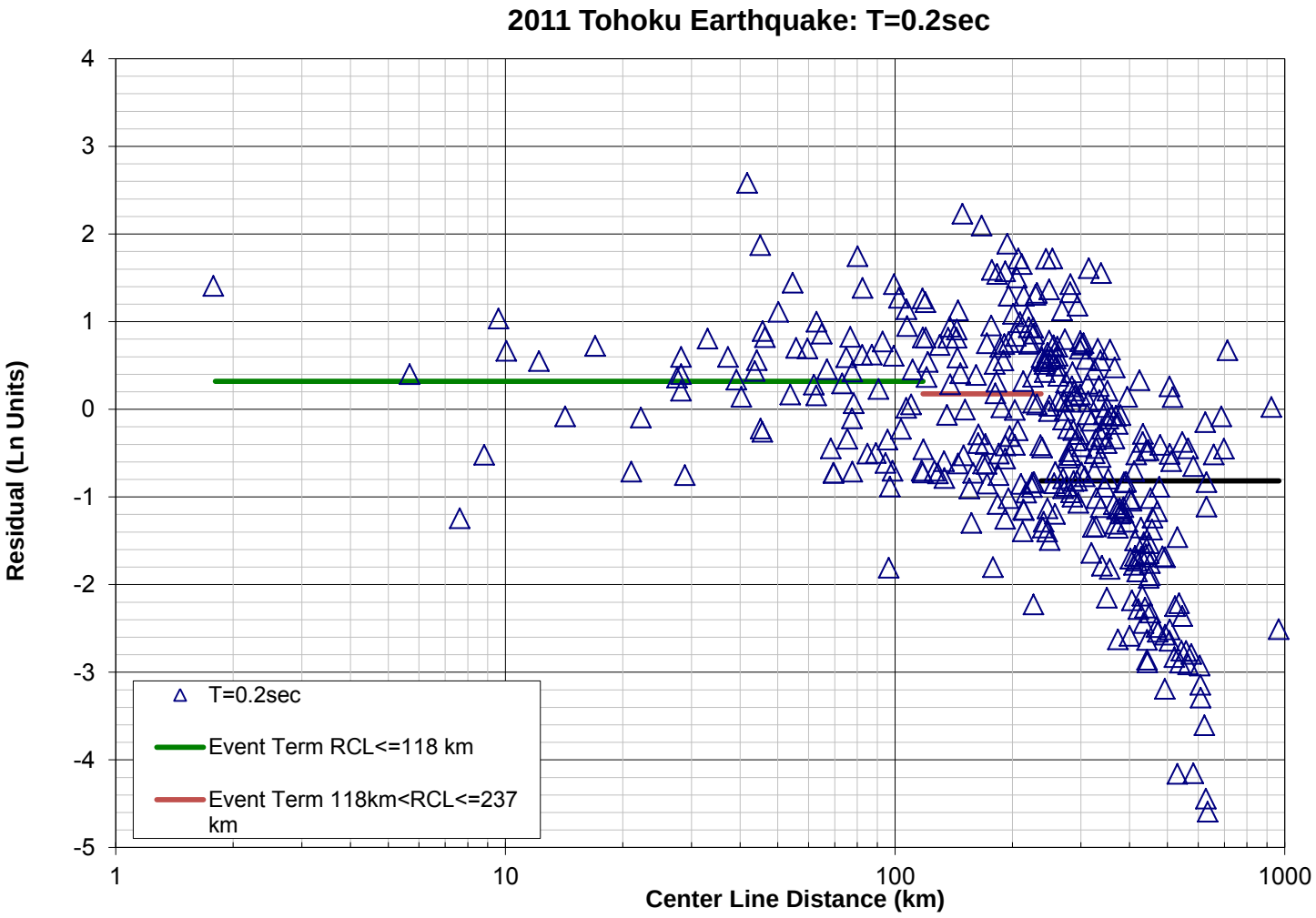




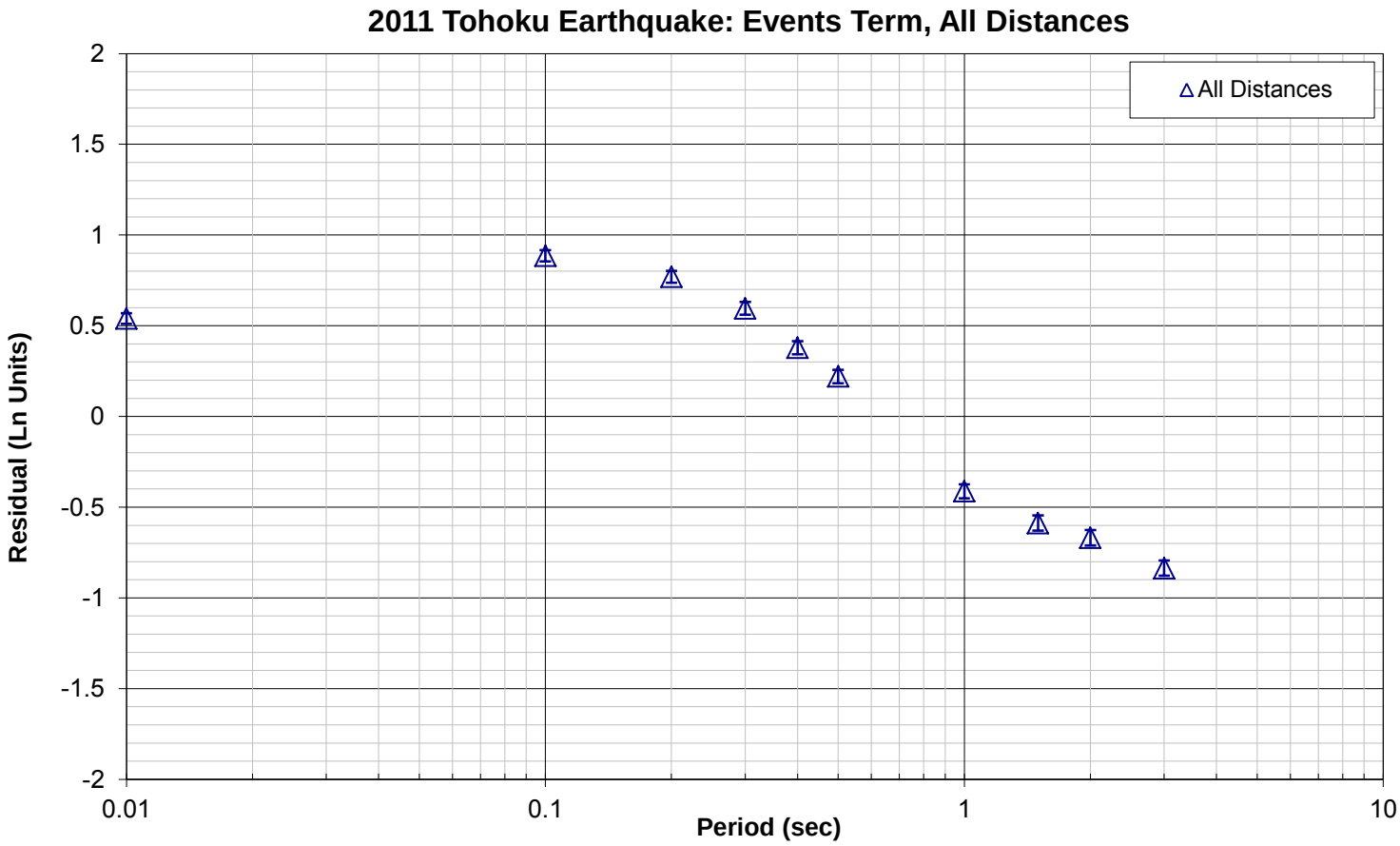
Tohoku (PGA)


2011 Tohoku Earthquake: T=0.2sec
Residual (Ln Units)
Center Line Distance (km)
4
3
2
1
0
-1
-2
-3
-4
-5
1
10
100
1000
T=0.2sec
Event Term RCL<=118 km
Event Term 118km<RCL<=237 km
Event Term RCL>237 km

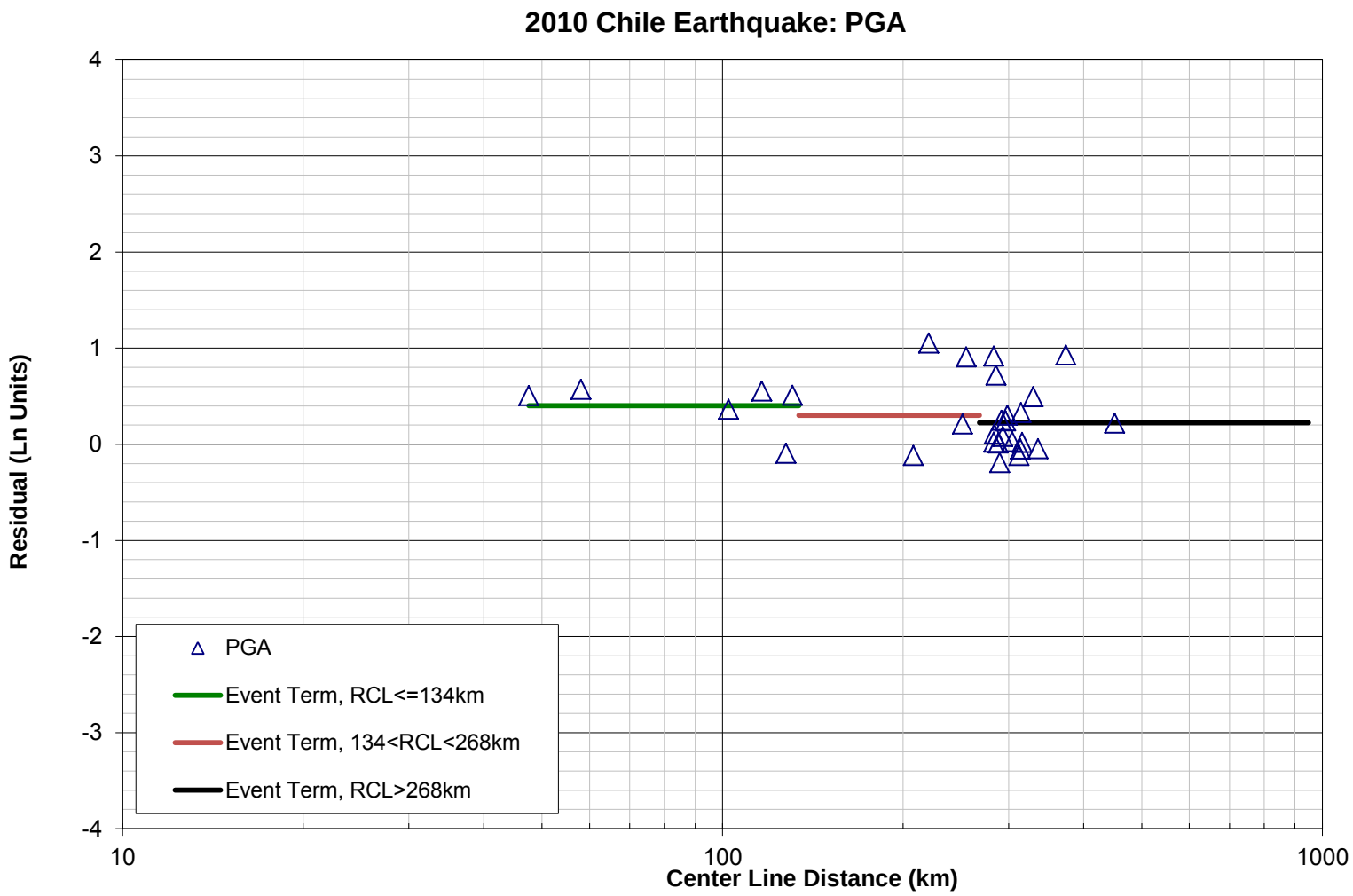
Tohoku (T=1 sec)



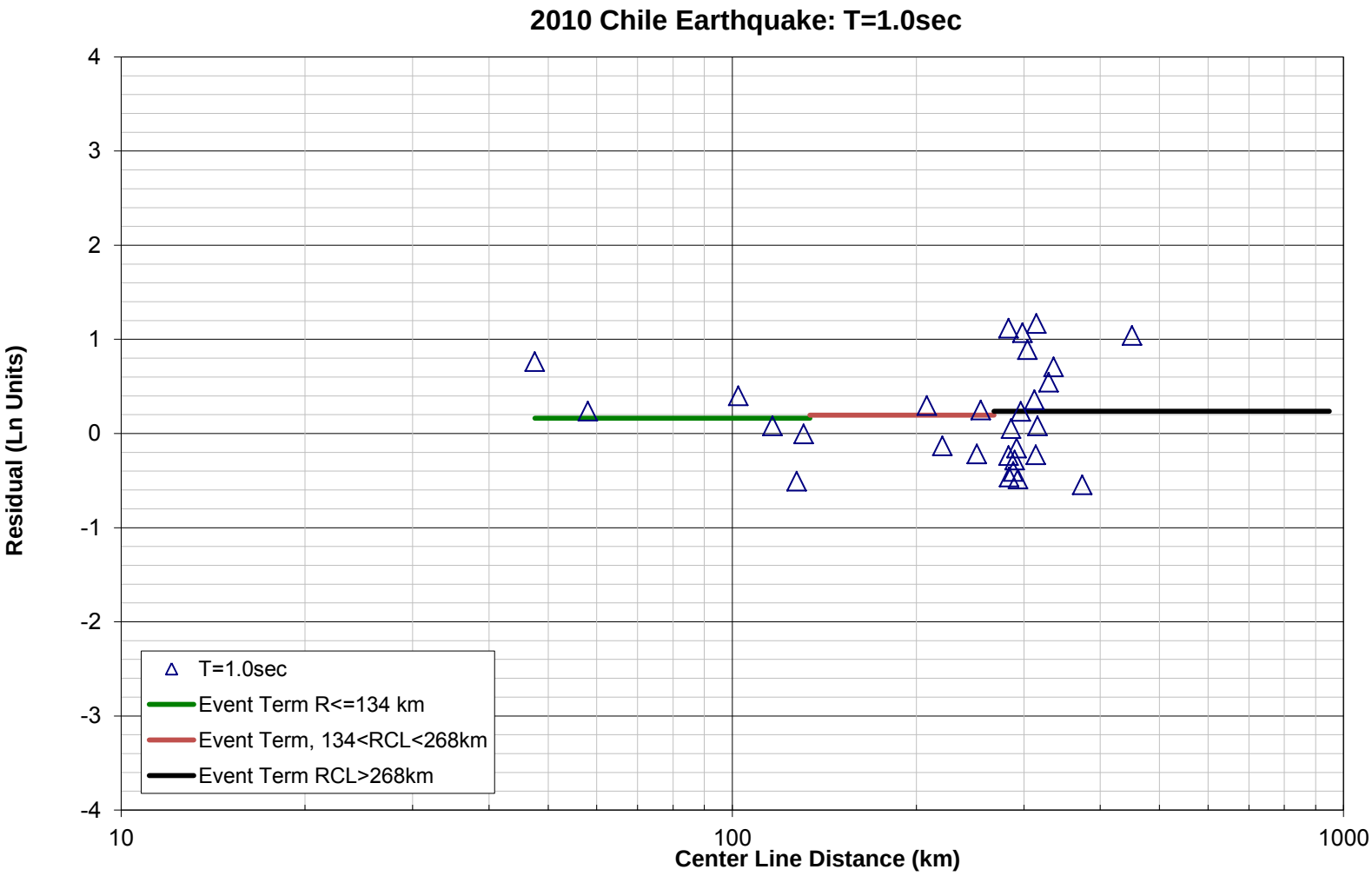
Tohoku (Rrup< 100 km)



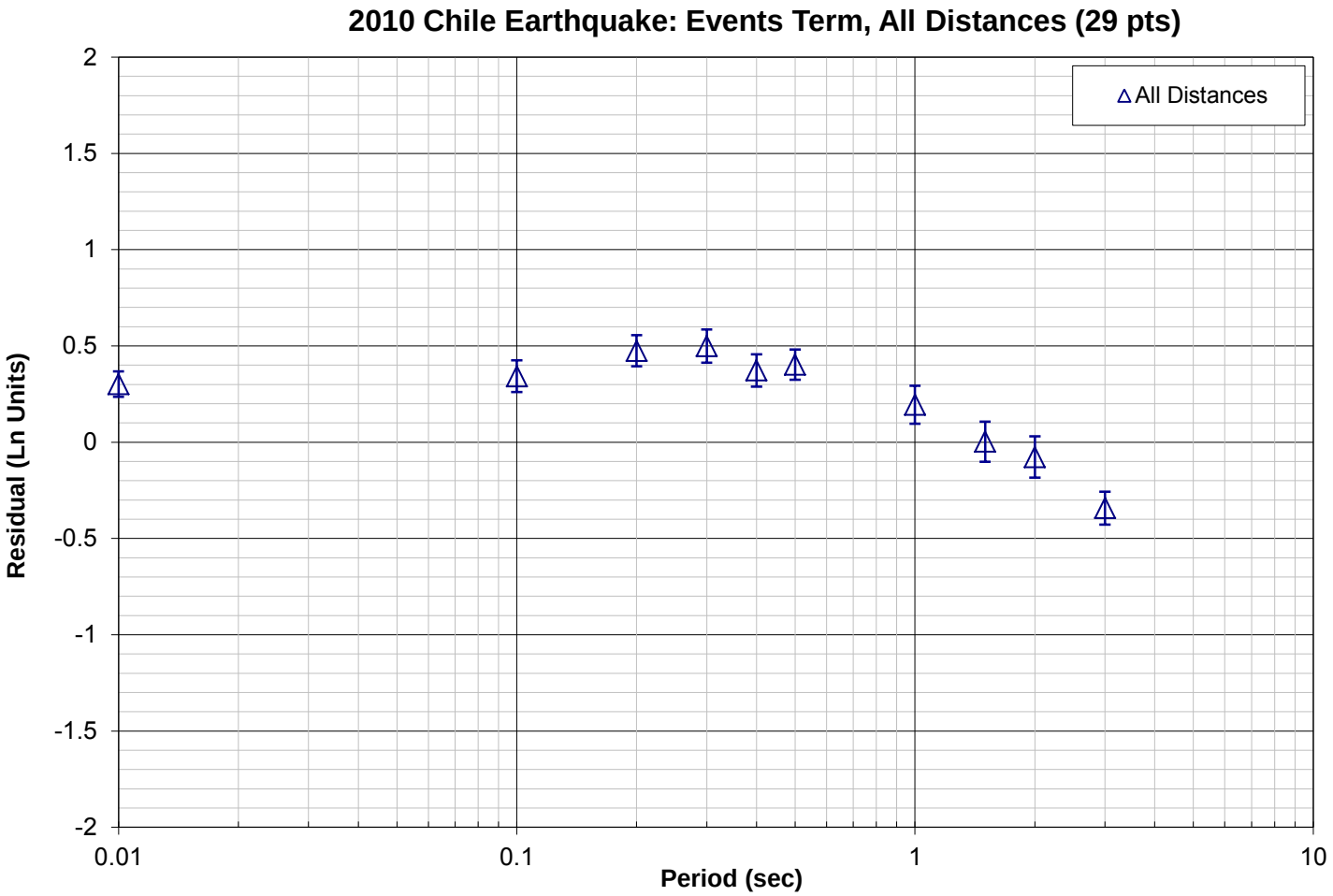
2010 Chile (PGA)

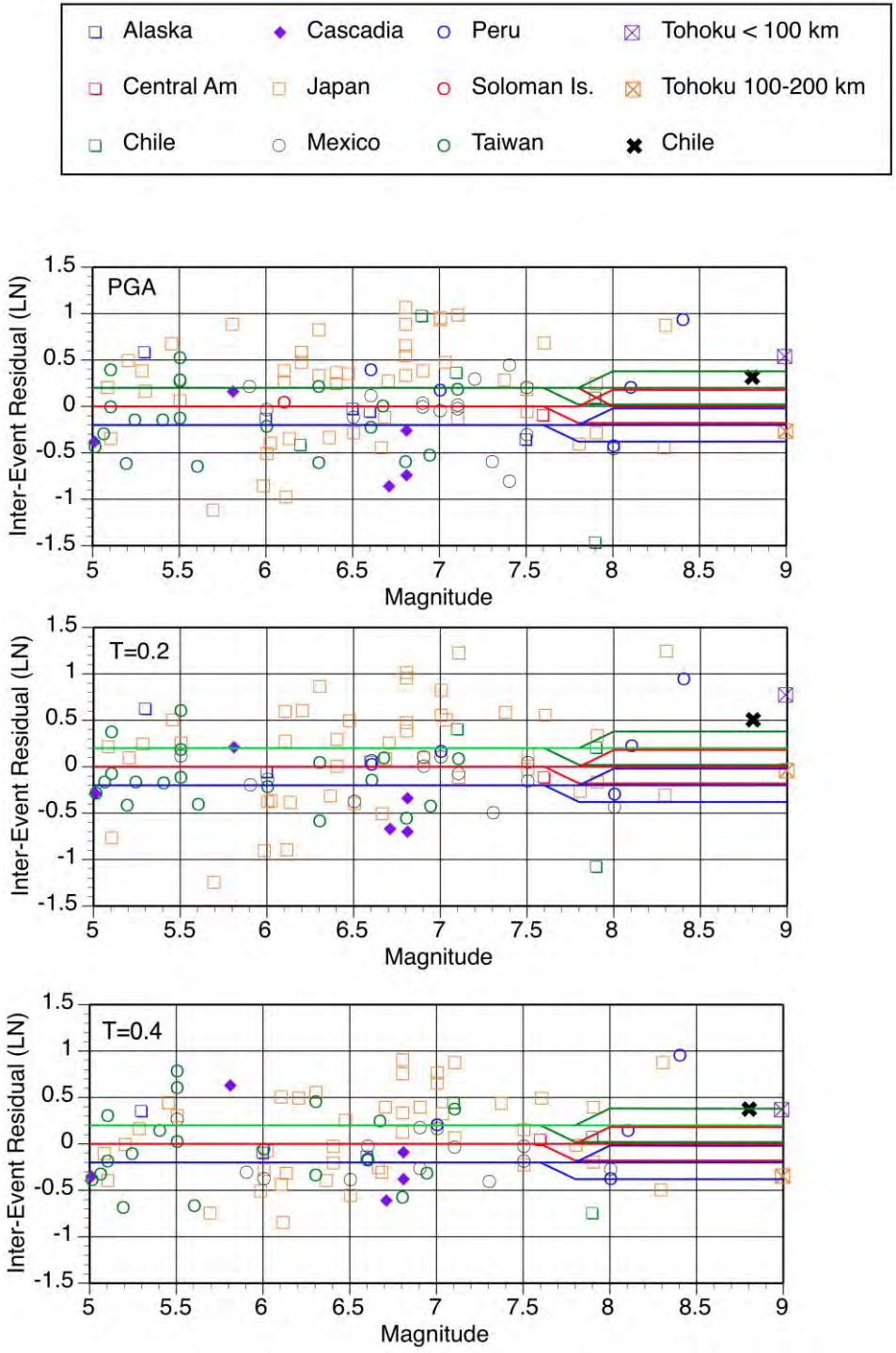


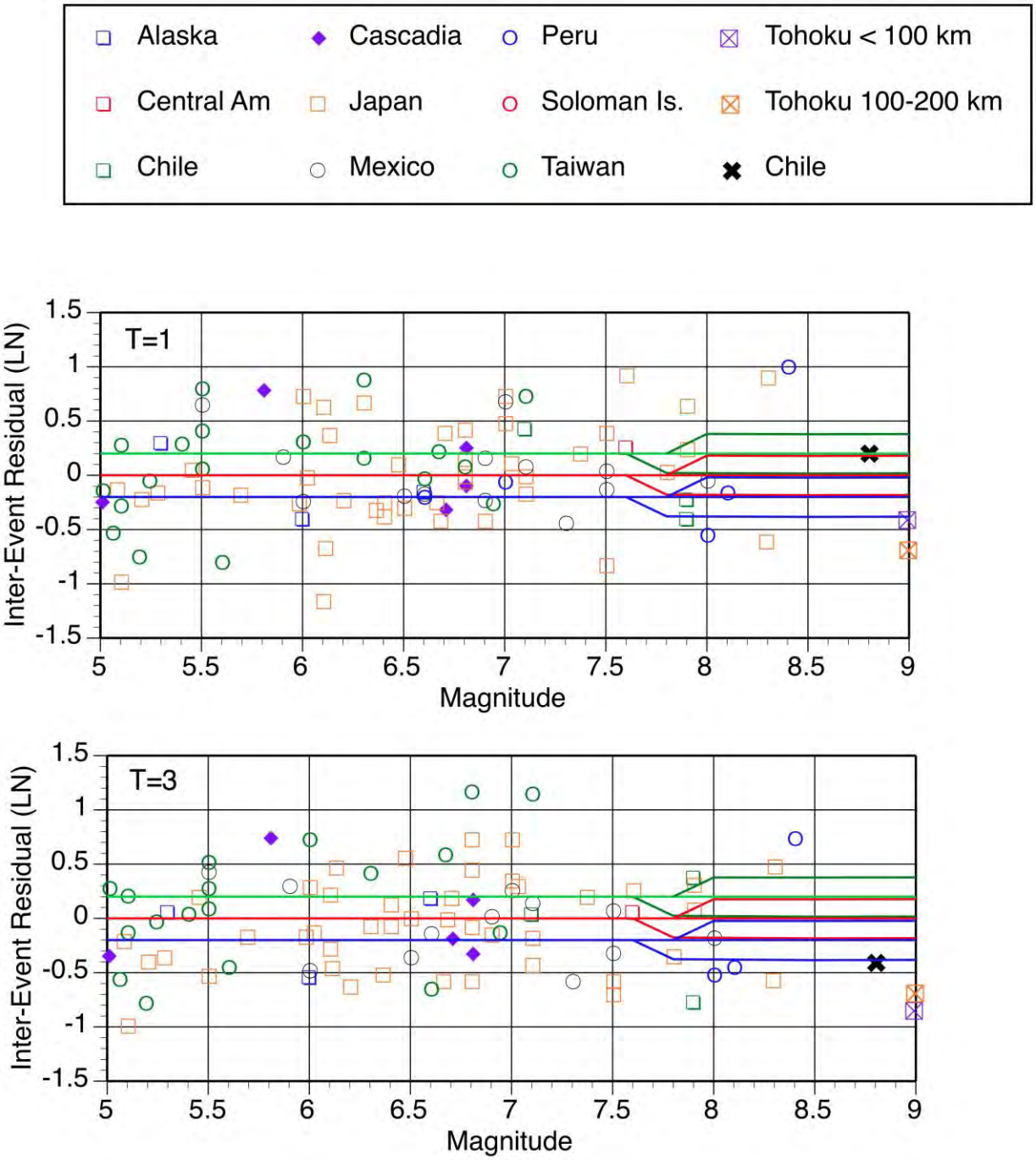
2010 Chile (T=1 sec)



2010 Chile


2010 Chile Earthquake: Events Term, All Distances (29 pts)
All Distances
Residual (Ln Units)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0.01
0.1
1
10
Period (sec)

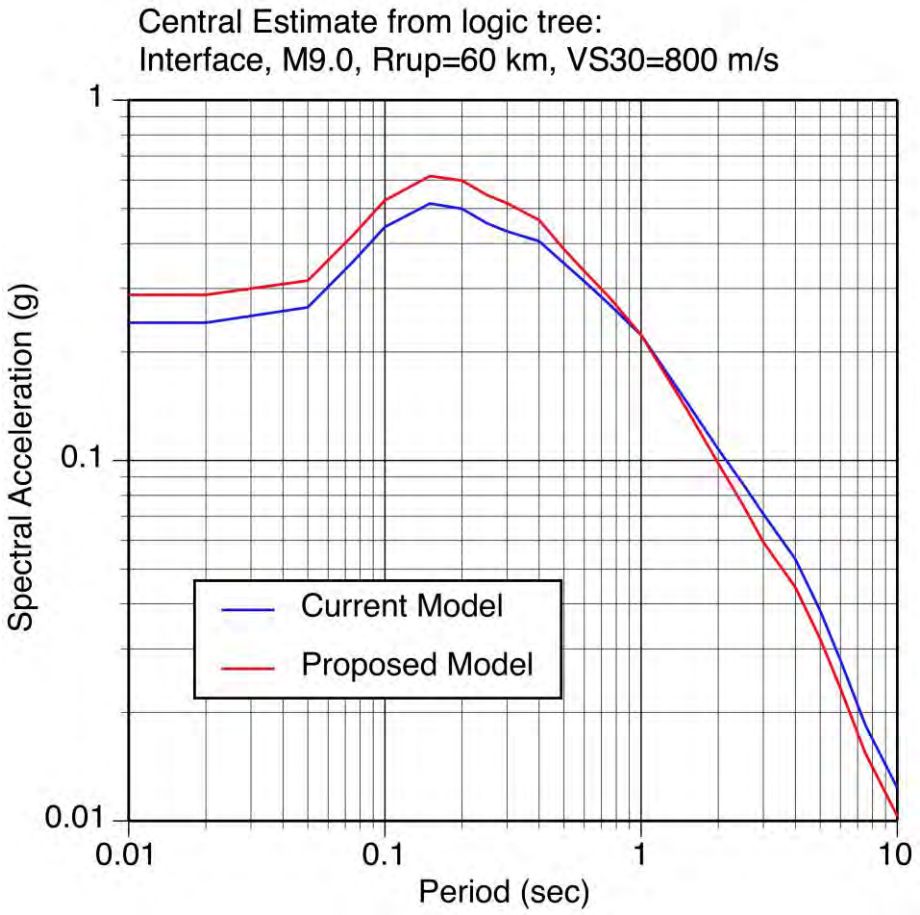

Alaska
Cascadia
Peru
Tohoku < 100 km
Central Am
Japan
Soloman Is.
Tohoku 100-200 km
Chile
Mexico
Taiwan
Chile
PGA
T=0.2
T=0.4
Inter-Event Residual (LN)
Magnitude
1.5
1
0.5
0
-0.5
-1
-1.5
5
5.5
6
6.5
7
7.5
8
8.5
9


Alaska
Cascadia
Peru
Tohoku < 100 km
Central Am
Japan
Soloman Is.
Tohoku 100-200 km
Chile
Mexico
Taiwan
Chile
T=1
Inter-Event Residual (LN)
Magnitude
T=3
Inter-Event Residual (LN)
Magnitude

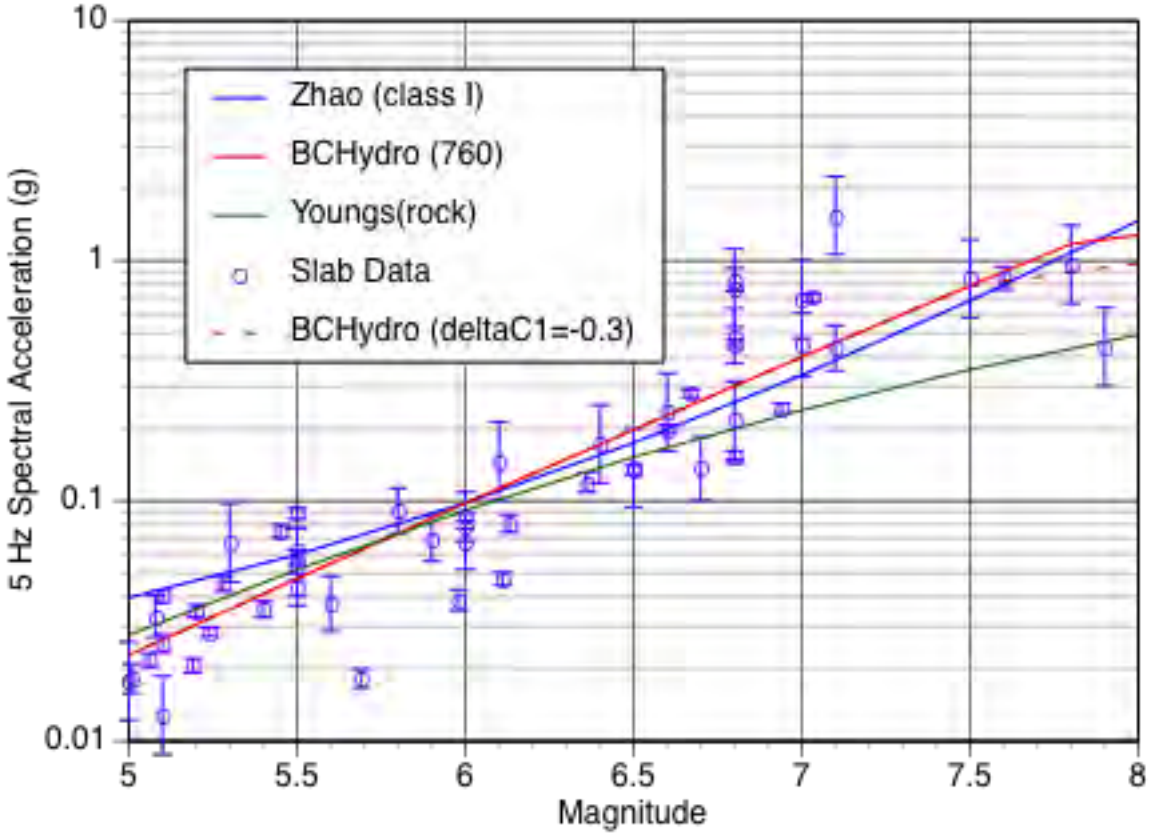
Revision to DeltaC1 Terms for Mega Thrust

Period (sec)	Lower Value	Central Value	Upper Value
PGA	0.0	0.2	0.4
0.3	0.0	0.2	0.4
0.5	-0.1	0.1	0.3
1.0	-0.2	0.0	0.2
2.0	-0.3	-0.1	0.1
3.0	-0.4	-0.2	0.0

Effect of Change in Delta C1



Break in Mag Scaling for Slab Eqk?



For Slabs Eqk

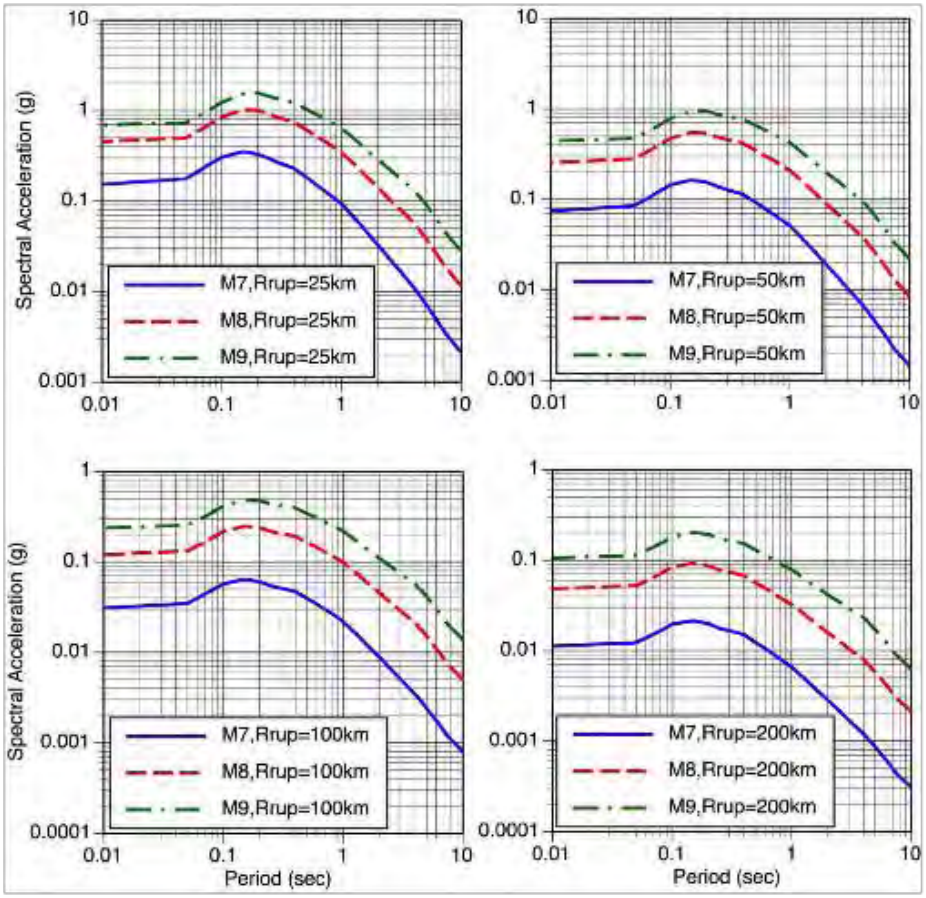
Lower: $\Delta C1 = -0.5$

Central: DC1 = -0.3

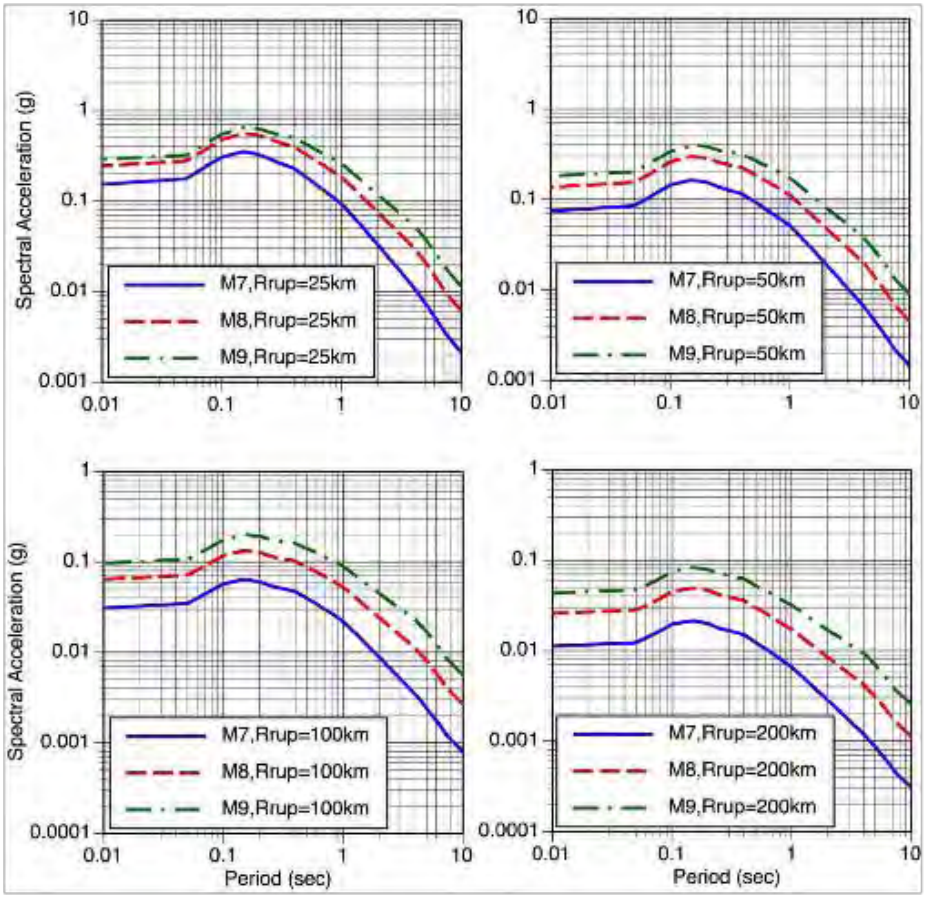
Upper: DC1 = -0.1

Strengths and Weaknesses

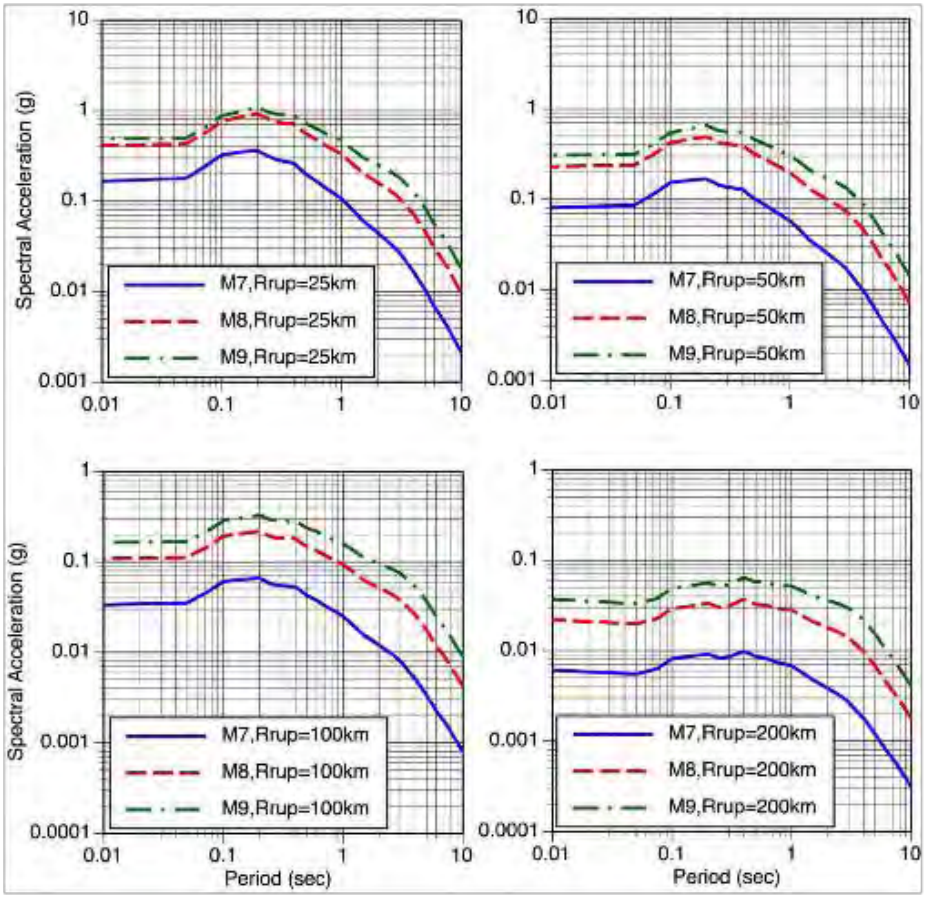
- Strengths
  - Based on large data base with consistent meta data
  - Allows for adjustment of scaling at large magnitudes through deltaC1 term
  - Evaluates regional variation in constant term
- Weaknesses
  - No regional variation in VS30 scaling and gamma (Q) terms
  - No Ry dependence, over-estimates ground motion off end of megathrust
  - Forearc/backarc scaling may also reflect different Q in Japan



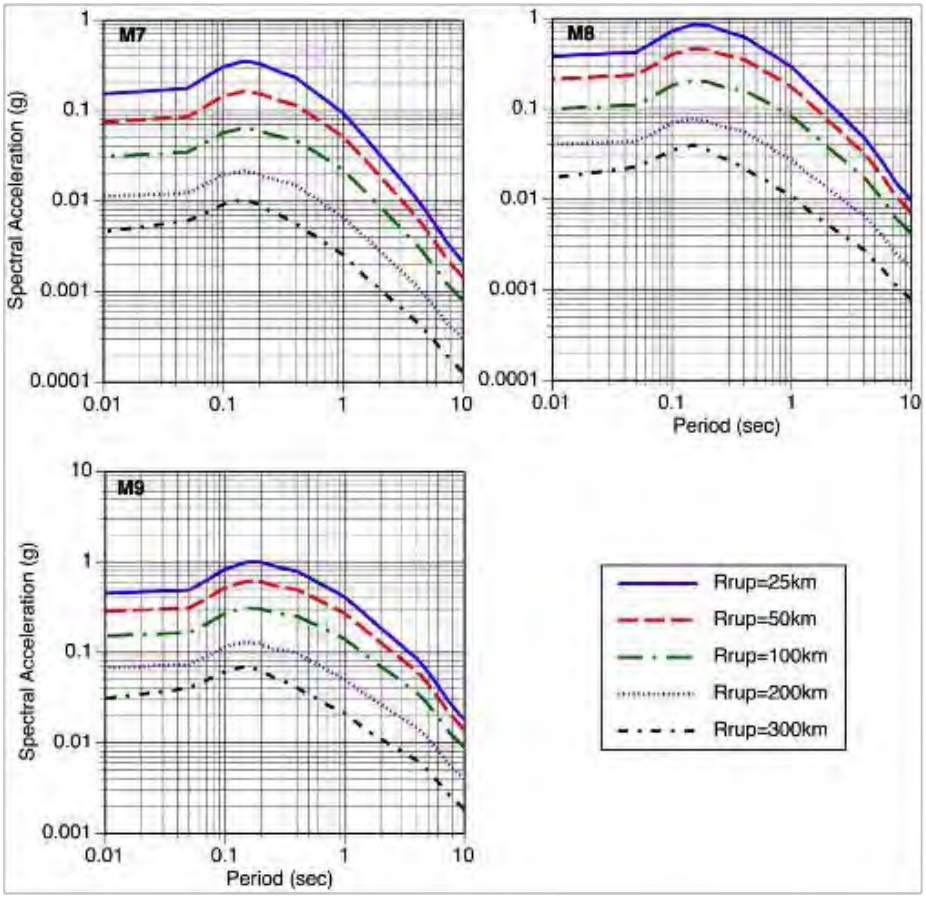
BC hydro PSHA07DS Ground Motion Modelling Report	Magnitude scaling of the median spectra for interface earthquakes for Forearc station locations and △C1=0.5	**Fig. 3-36b**	
DSGN: NAA CHKD: NJG DATE: Nov 2010		REPORT No.: E658-3	



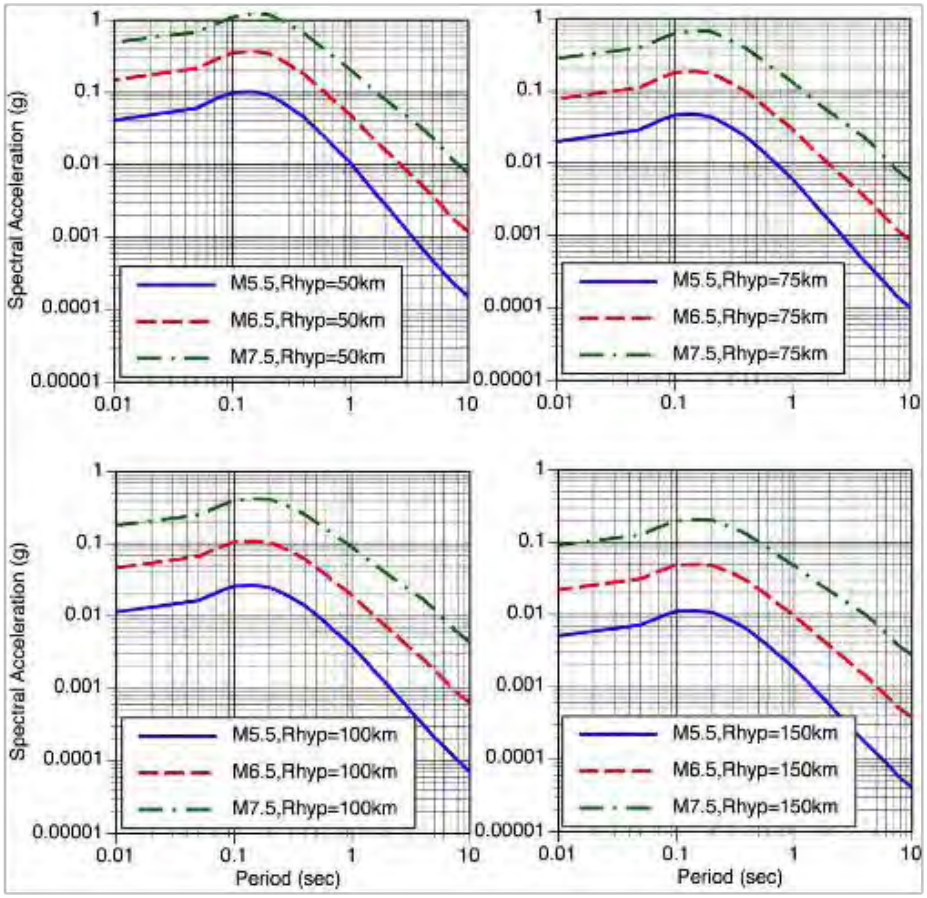
BCHydro PSHA07DS Ground Motion Modelling Report	Magnitude scaling of the median spectra for interface earthquakes for Forearc station locations and △C1=0.5	**Fig. 3-36c**	
DSGN: NAA CHKD: NJG DATE: Nov 2010		REPORT No.: E658-3	



BCHydro PSHA07DS Ground Motion Modelling Report	Magnitude scaling of the median spectra for interface earthquakes for Backarc station locations and △C1=0.0	**Fig. 3-36d**	
DSGN: NAA CHKD: NJG DATE: Nov 2010		REPORT No.: E658-3	



BCHydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	Distance scaling of the median spectra for interface earthquakes for Forearc station locations and △C1=0.0	Fig. 3-37a REPORT No.: E658-3



BC hydro PSHA07DS Ground Motion Modelling Report DSGN: NAA CHKD: NJG DATE: Nov 2010	Magnitude scaling of the response spectra for intraslab events. These are for a hypocentral depth of 50 km and Forearc station locations	Fig. 3-43 REPORT No.: E658-3